

CPWF Project Report

Improved fisheries productivity and management in
tropical reservoirs

Project Number 34

C. Béné (Project Leader), E.K. Abban, S.H. Abdel-Rahman,
S. Ayyappan, R. Brummett, H.R. Dankwa, A.K. Das, O.A.
Habib, P.K. Katiha, J. Kolding, N. Obirih-Opareh, J.K. Ofori, M.
Shehata, N.P. Shrivastava, and K.K. Vass

for submission to the



May 30, 2009

ACKNOWLEDGEMENTS

This project was funded by the Challenge Programme on Water and Food. Matching funds were also provided by the following institutes: the WorldFish Center; the Water Research Institute (Ghana); the National Institute of Oceanography and Fisheries (Egypt); the Lake Nasser Development Authority (Egypt); the Central Inland Fisheries Research Institute (India); the University of Bergen (Norway); and the Science and Technology Policy Research Institute (Ghana).

In addition to the principal investigators listed as main authors, the following individuals have also participated to the project research and/or contributed to the redaction of this report (listed by alphabetic order): Dr. Adel Aly Ahmad (NIOF), Mr. K. Agboga, (WRI, Ghana), Mr. S. K. Agyakwa (WRI), Mr. F.J. Akpabey (WRI), Mrs. M. Amu-Mensah (WRI), Mr. H. Ammar (LNDA), Mr Shyam Lal Arya (CIFRI India), Mr. Surajit Kangsa Banik (CIFRI India), Mr. Satish Kumar Bara (CIFRI India), Mr. Nirmal Kumar Biswas (CIFRI India), Dr. M. I. Khan, Bundelkhand University (India), Dr. Reda Fishar (NIOF), Dr. Alaa M. El Far (NIOF), Mr. Yaser El Sangak (NIOF), Dr. Emad Hamdy (NIOF), Dr. Alaa EIDin El Haweet (NIOF), Dr. Ola Ezz EIDin Taha (NIOF), Dr. Radwan Gad Ek Rab Abdel Elah (NIOF), Mr. Shubhodeep Ghosh (CIFRI India), Dr. Mohammed Hamdy (NIOF), Mr. I. Iwamoto (LNDA), Mr. A. Y. Karikari (WRI), Prof. Jacques Lemoalle (IRD- UMR G-Eau France), Dr. Mohammed Saad Abdel Kariem (NIOF), Shri M. Karthikeyan (CIFRI India), Shri S. K. Mandal (CIFRI, India), Mr. Hisham Abdel Mowla (NIOF), Mr M. Nageb (LNDA), Mr I. Omar (LNDA), Miss Amany Abd El Rassoul (LNDA), Dr. M. K. Pal, Vidyasagar University (India), Dr. D.S. K. Rao (CIFRI India), Mrs Anubha Saxena (CIFRI India), Ms Sanchita Sarkar (CIFRI India), Dr. V. K. Sharma (CIFE, Mumbai), Dr. V. V. Sugunan, (ADG, ICAR, New Delhi), Dr. Ashwani Wangneo (Barkatulla University India), Dr. Aly Yousef (NIOF), Dr. Shawki Zaki Sabaa (NIOF), Mr. M. Zaki (LNDA), Prof. Paul van Zwieten (Wageningen University, Netherlands). Their respective contribution is fully acknowledged.



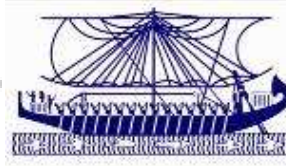
WorldFish Center



WRI



Univ Bergen



NIOF



LNDA



CIFRI

Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

“Improved fisheries productivity and management in tropical reservoirs”

The objective of the project was to contribute to the current research on reservoirs enhancement fisheries in tropical countries through the implementation of a series of action-research activities implemented in two small reservoirs in the Indo-Gangetic basin in India, and two very large reservoirs in Africa, the Lake Nasser (Egypt), and the Volta Lake (Ghana). Socio-institutional analyses were also conducted in these reservoirs to improve our knowledge regarding some of the main social processes that influence reservoir productivity. Overall the results of the project stress that while the natural biophysical constraints of the reservoirs are important in defining the ecological production processes, it is the socio-economic settings characterizing the community/societies around the reservoirs that eventually shape the human production enhancement possibilities.

CPWF Project Report series:

Each report in the CPWF Project Report series is reviewed by an independent research supervisor and the CPWF Secretariat, under the oversight of the Associate Director. The views expressed in these reports are those of the author(s) and do not necessarily reflect the official views of the CGIAR Challenge Program on Water and Food. Reports may be copied freely and cited with due acknowledgment. Before taking any action based on the information in this publication, readers are advised to seek expert professional, scientific and technical advice.

Citation: Béné, C., Abban, E.K., Abdel-Rahman, S.H., Ayyappan, S., Brummett, R., Dankwa, H.R., Das, A.K., Habib, O.A., Katiha, P.K., Kolding, J., Obirih-Opareh, N., Ofori, J.K., Shehata, M., Shrivastava, N.P. and Vass, K.K. 2009. Improved fisheries productivity and management in tropical reservoirs. *CPWF Project Number 34: CGIAR Challenge Program on Water and Food Project Report series*, www.waterandfood.org.

Fish and Gender:

Reflecting our recognition of the central role played by women in many different aspects of small-scale fisheries in the world, only gender-sensitive words have been used in this report. In particular the word ‘fisherman’ which carries an inappropriately gender bias has been systematically replaced by gender-neutral terms such as ‘fisher’, ‘fisherfolk’ or ‘fishing community’. Exceptions only hold for the particular term ‘chief fisherman’ or to refer to existing official names of organizations (e.g. “the Fisherman Cooperative Society” of Dahod reservoir in India).

CONTENTS

Acknowledgements	2
Contents	4
List of Tables	7
List of Figures	8
List of Illustrations	9
List of Abbreviations and Acronyms	10
List of Abbreviations and Acronyms	10
Research highlights	11
Executive summary.....	13
Introduction	17
Project Objectives.....	19
Section 1: Fisheries enhancement tools	19
1.1. Bio-physical and ecological dynamics of tropical reservoirs	19
1.1.1. Indo-Gangetic Basin	19
Data collection.....	19
Results.....	20
Morphometric characteristics	20
Relative Lake Level Fluctuation	21
Case studies.....	22
Discussion	26
1.1.2. Volta Basin.....	28
Methods	28
Bio-Physical Studies.....	28
Fish Catch Assessment	28
Results.....	29
Bio-physical parameters	29
Fish Catch Assessment:.....	30
Discussion	33
Bio-physical parameters	33
Fish Catch Assessment.....	33
1.1.3. Lake Nasser	34
Methods	34
Results.....	35
Discussion	38
Enclosures and restocking of enclosures.....	39
Increasing productivity through species introductions.....	39
1.1.4. General consideration on reservoir productivity	39
1.2. Fisheries enhancement tools: implementation	41
1.2.1. General introduction of the section	41
1.2.2. Cage Culture in Lake Volta.....	41
Justification and choice of the fisheries enhancement techniques.....	41
Methods	42
Results.....	44
Discussion	46
1.2.3. Cage Culture and pens in the Indo-Gangetic Basin	48
Choice of sites and fisheries enhancement models in the Indo Gangetic Basin	48
Methods	49
Enhancement Strategies.....	49
Raising of fingerlings in cages.....	50
Impacts of the intervention.....	51
Dahod	51
Pahuj	52
1.2.4. Fish enclosure in the Nile Basin.....	53
Choice of sites and fisheries enhancement models in the Nile Basin	53
Methods	54
Results.....	56
Removal of predators.....	56
Releasing of <i>O. niloticus</i> fingerlings and fries.....	56
Fish catch	57
Experimental fishing	58
Length-weight relationship of <i>O. Niloticus</i> at enclosures	58

Fish catch inside enclosures	59
Fish catch outside enclosures	60
Concluding remarks on Lake Nasser enclosures	61
1.3. Section 1's General Discussion	61
1.4. Section 1's Conclusion	62
Section 2: Socio-institutional analysis	63
2.1. General introduction to the section	63
2.2. Reservoir productivity and institutional arrangements in India	63
2.2.1. Introduction	63
2.2.2. Methods	64
2.2.3. Results and analysis	65
2.2.4. Discussion	70
2.3. Institutions of Lake Nasser fishery and their impact on the reservoir productivity	72
2.3.1. Introduction	72
2.3.2. Impacts of macro-economic reforms on the fishery productivity	72
The context	72
Smuggling, issue No.1 in Lake Nasser	73
2.3.3. Impact of share contract on Lake Nasser fishery's productivity	74
Owners	75
Renters	76
Partners	76
Laborers	76
Statistical analysis	77
Access to Capital	79
2.4. Socio-institutional analysis of Lake Volta fishery: the case of <i>acadjas</i>	80
2.4.1. Introduction	80
2.4.2. Methods	81
2.4.3. Results	81
2.4.4. Discussion	84
2.5. Section 2's General Discussion	84
2.6. Section 2's Conclusion	87
Section 3: Strengthening stakeholders' capacities	87
3.1. General introduction	87
3.2. Scheduled workshops	88
3.3. Post harvest interventions	89
3.3.1. Improving fish processing in Lake Nasser	89
The context	89
Statistical analysis	90
Discussion	91
3.3.2. Improving fish trading in India	91
Provision of ice-box and transportation	91
Establishment of a micro-finance system	92
3.3.3. Improving fish processing in Ghana	93
Background	93
Involvement of the project	93
3.4. Section 3's General Discussion	95
3.5. Section 3's Conclusion	95
General discussion and conclusion	96
Ecological consideration on fishery reservoir productivity: lessons from CP34	96
Socio-institutional considerations on reservoir fishery productivity	97
Conclusion	98
Outcomes and Impacts	100
Description of the Project's Main Impact Pathways	100
International Public Goods	104
New Insights	104
Tools and methodology	105
Datasets	105
Publications	106
Partnership Achievements	107
Recommendations	108
Publications	109
Peer-reviewed Journals	109
Conference Proceedings	109

Contents **CPWF Project Report**

Research papers.....	111
Technical Manuals.....	111
Ph.D Thesis or dissertation	111
Project reports	112
Bibliography	113
Project participants.....	117
Appendix : Abstract of peer-reviewed publications.....	118

LIST OF TABLES

Table 1.1. Distribution (in %) of the studied reservoirs according to area across Indian IGB states.

Table 1.2. Morphometric and hydrological features of Indo-Gangetic basin reservoirs

Table 1.3. Comparative account of the project's two case studies' reservoirs

Table 1.4. Fish catch composition at Dahod reservoir during pre-project years

Table 1.5. Fish catch composition at Pahuj reservoir during pre-project years

Table 1.6. Fish yield in reservoirs of five out of 12 Indo-Gangetic Basin States

Table 1.7. Fish production potential and actual fish yield in selected Indo-Gangetic Basin reservoirs

Table 1.8. Comparison of water parameters from previous studies and the current one

Table 1.9. Catch per Unit of Effort (CPUE) by fishing gear and estimated annual fish catch from the Volta Lake at Dzemeni from March 2007 to June 2008.

Table 1.10. Species composition in weight (Wt%) and number (No%) for different gear types in Lake Nasser during the study period based on 1529 samples

Table 1.11. CPUE (Kg/50m-net/ night or shot) for different gear types and parts of Lake Nasser during the study period

Table 1.12. Size indicators in standard length (SL) and total weight (Wt) for different gear types and parts of Lake Nasser during the study period.

Table 1.13. Construction costs for a 48m³ small-scale aquaculture cage manufactured from locally available materials in Dzemeni, Ghana (1 USD = 0.92 Ghana ¢).

Table 1.14 a. Fish stocking, growth and harvest data for the first of two pilot cage trials

Table 1.14 b. Fish stocking, growth and harvest data for the second of two pilot cage trials

Table 1.15. Economic analysis (1 US\$ = 1.12 Ghana ¢).

Table 1.16. Cost of production, revenues and return on investment.

Table 1.17. Proportion of large (>300g), medium (250-300g) and small (<250 g) fish obtained over the six month trial

Table 1.18. Mean ± standard deviation of water quality parameters measured bi-monthly (n=10) at mid-cage depth (1 m)

Table 1.19. Impact of interventions on fish catch of Dahod reservoir

Table 1.20. Impact of interventions on fish catch of Pahuj reservoir

Table 2.1. Variables considered in the analysis

Table 2.2. Normality Test (Kolmogorov-Smirnov)

Table 2.3. Result of the BEST analysis for the bio-physical model

Table 2.4. Result of the BEST analysis for the general model

Table 2.5. Principal Component Analysis

Table 2.6. OLS model between productivity and the variables' coordinates along PC1

Table 2.7. SIMPER analysis with a cut-off threshold set at 40%

Table 2.8. Pairwise Multiple Comparison Procedures for both depth and stock density

Table 2.9. Statistic summary of the reservoirs grouped by arrangements

Table 2.10. Socio-economic statistics of the fishers operating in Lake Nasser

Table 2.11. 2SLS estimates

Table 2.12. Statistics summary of the socio-economics data

Table 3.1. Series of workshops run by the projects as part of the capacity building objective.

Table 3.2. Aggregated cost of the wooden cabin (for the 3 cabins)

Table 3.3. Number of spoiled salted fish tins

Table 3.4. Mann-Whitney Rank Sum Test

Table 3.5. Comparative analysis of production level and retail price before and after CP34 intervention

Table 3.6. Comparative analysis of catch and return per unit of effort before and after CP34 intervention

Table 3.7. Characteristics of the two fish smoker ovens

LIST OF FIGURES

- Fig.1.1. Relation between fish productivity and index of Relative Lake Level Fluctuation in 21 lakes of the Indo-Gangetic Basin.
- Fig.1.2. Maps of Dahod reservoir (left) and Pahuj reservoir (right).
- Fig.1.3. Planktonic population in Dahod (top) and Pahuj (bottom).
- Fig.1.4. Primary production trends in Dahod and Pahuj reservoirs
- Fig.1.5. Distribution of productivity in 98 Indo-Gangetic reservoirs.
- Fig.1.6. Map of the Volta Lake showing the various strata and the study areas.
- Fig.1.7. Length distribution of all species in catch of all gears deployed in Stratum II - Volta Lake
- Fig.1.8. Catch composition of each fisher employed in the study during the period March 2007 to June 2008
- Fig.1.9. Overall fish catch composition (left=number; right=weight) from March 2007 to June 2008.
- Fig.1.10. Changes in fish species composition from all fishing gears employed in the study from March 2007 to June 2008.
- Fig.1.11. Standardized weekly CPUE of the different commercial gear categories sampled in the study for all species from March 2007 to June 2008.
- Fig.1.12. Total number of days fished over 15 months and average catch per fishing day (kg/day) for the 11 fishers engaged in the sampling scheme.
- Fig.1.13. Map of Lake Nasser
- Fig.1.14. Zooplankton abundance at the six studied *khors*
- Fig.1.15. Fish landing from Lake Nasser from 1965 to 2005 (LNDA Statistics)
- Fig.1.16 A. Plot of total yield (kg) on surface area (ha) for reservoirs in China; Thailand; Sri Lanka; Philippine and in Indonesia - B: Plot of total yield on surface area for reservoirs in Cuba; Mexico; Brazil, Peru, in Costa Rica, and others - C. Plot of total catch on surface area for African lakes and reservoirs - D. Plot of total yield on surface area for reservoirs in Madhya Pradesh, Rajasthan, Uttar Pradesh, Himachal Pradesh and Bihar
- Fig.1.17. a Growth pattern of *Oreochromis niloticus* trial 1; b: trial 2
- Fig.1.18. Trends in key water quality parameters sampled every 8 weeks 10 m above (solid bar on the left) and 30 m below (hashed bar on right).
- Fig.1.19. Location of the three *khors* where enclosure experiments were conducted
- Fig.1.20. Vertical section of the net used for enclosure
- Fig.1.21. Water Depth and Surface Area of two enclosures at two water levels
- Fig.1.22. Mean monthly catch per unit effort (kg/boat/day) inside two enclosures for the period of the experiment
- Fig.1.23. Total monthly catches (kg) by small (< 1 kg) and large (> 1 kg) tilapias, Nile perch and 'others', inside Ambercab and Wadi abyad enclosures
- Fig.1.24. Frequency distribution of body length of tilapia species by different mesh sizes
- Fig.1.25. Length – Weight relationship of *O. niloticus* inside enclosures
- Fig.1.26. Length – Weight relationship of *S. galilaeus* inside enclosures
- Fig.1.27. Mean body weight (g) of *O. niloticus* and *S. galilaeus* inside enclosures
- Fig.1.28. Total catch (kg) for all species inside
- Fig.1.29. CPUE (kg/boat/day) for all species inside the enclosures
- Fig.1.30. Total catch (ton) for all species outside and inside enclosures during months of January to April by year
- Fig.1.31. CPUE (kg/boat/day) for all species outside and inside enclosures during months of January to April by year
- Fig.2.1. Draftman plots and correlation coefficients between variables
- Fig.2.2. The two first axes of the Principal Component Analysis conducted on the explanatory variables
- Fig.2.3. The size of the bubbles, proportional to the productivity, suggest a decreasing gradient along axis 1
- Fig.2.4. Evolution of the landings for fresh, salted and total landing from Lake Nasser's fishery
- Fig.2.5. The four different contracts and their characteristics
- Fig.2.6. Number of fishing operation per fisher per week
- Fig 2.7. Catch per boat per year (in kg)

- Fig.2.8. Lorenz curves and Gini coefficients computed for the four groups: owners, non-owners, non-*acadjas* villagers, and 'aggregate' group (owners + non-owners)
- Fig.2.9. Comparison of the incomes of *acadja* owners with the rest of their respective quartile population.
- Fig.3.1. proportion of tins spoiled inside and outside the wooden cabins

LIST OF ILLUSTRATIONS

- Photos 1.1. Cages used for the trial (Lake Volta)
- Photos 1.2. Left: sorting fish harvested from cage trial into size groups; Right: selling of fish harvested from the cage
- Photo 1.3. Example of small scale cage trials being implemented by individuals in the lower Volta River
- Photos 1.4. Cages being installed on the Dahod (left) and Pahunj (right) reservoirs.
- Photos 1.5. Left: fingerling raising in Cages in Pahunj reservoir. Right: a harvest of major carps at Pahunj reservoir being examined.
- Photos 1.6. Installation of the net in the *chor* entrance
- Photos 3.1. Consensus building workshops in Dahod (left) and Aswan (right)
- Photos 3.2. Top: traditional salting technique: Bottom: three wooden houses built up on site for salting operations in improved hygienic conditions
- Photos 3.3. Left: bicycles fitted with iceboxes to improve quality of fish during transportation. Right: Market survey.
- Photos 3.4. Chorkor-Smoker and FRI-Smokers

LIST OF ABBREVIATIONS AND ACRONYMS

ARDEC	Ghanaian Aquaculture Research and Development Centre
AFW	Average Final Weight
AIW	Average Initial Weight/growth period (days)
APHA	American Public Health Association
BNT	big net traps
BOD	Biological oxygen demand
BPEDTR	Bio-physical and ecological dynamics of tropical reservoirs
CBW	Consensus building workshop
CCSW	Community Capacity Strengthening Workshops
CGIAR	Consultative Group International Agricultural Research
CIFRI	Central Inland Fisheries Research Institute (India)
COD	Chemical oxygen demand
CP 34	Challenge Programme Water for Food Project Number 34
CPUE	Catch Per Unit Effort
CPWF	Challenge Programme Water for Food
CSIR	Council for Scientific and Industrial Research (CSIR, Ghana)
CWPFAS	Crop water productivity, fisheries and aquatic ecosystems
DO	Dissolved Oxygen
FAO	Food and Agriculture Organization
FCR	Food conversion ratios
FET	Fisheries Enhancement Tools
FPI	Fish productivity Index
GH	Gurf Hussein
GN	Gillnets of various
IGB	Indo-Gangetic Basin
IPG	International Public Goods
IRD	Institut de Recherche pour le Développement UMR G-Eau France
KR	<i>Khor</i> Korosko
LNDA	Lake Nasser Development Authority (Egypt)
MBT	medium basket traps
NIOF	National Institute of Oceanography and Fisheries (Egypt)
PCA	Principal Component Analysis
PRS	Project Report series
ROI	Cost of production, revenues and return on investment
RLLF	Relative Lake Level Fluctuation
SDI	Shoreline development index
SFD	State Fisheries Departments of India
SGR	Specific Growth Rate (%/day)
SIA	Socio-institutional analysis
SL	standard length
2SLS	two-stage-least square
SNK	Student-Newman-Keuls
SNT	small net traps
STEPRI	Science and Technology Policy Research Institute (Ghana)
TDS	Total dissolved solids
TE	Tushka East
TVBC	The total viable bacterial counts
TW	Tushka West
UOB	University of Bergen (Norway)
VDI	Volume Development Index

RESEARCH HIGHLIGHTS

An ever-growing number of small, medium and large reservoirs in the world are being built for irrigation or hydro-power purposes. While some fishing activities take place on these water-bodies, the productivity of their fisheries is often far below the identified biological potential. Yet, fisheries and their associated activities (fish processing and fish trading) have been recognized to play an important role in terms of food security and economic development in developing countries.

Reservoir fisheries productivity can be increased through a number of interventions combining better harvesting strategies, carefully adapted stock enhancements, and aquaculture activities. To achieve this untapped potential while securing ecosystem services such as water quality and biodiversity, a holistic approach and improved understanding involving both biological principles and stakeholder participation is necessary.

The main objective of this 3.5 year project was to contribute to the current research on reservoirs enhancement fisheries in tropical countries through the implementation of a series of action-research activities aiming at increasing the productivity of the water bodies and providing sustainable livelihood options to the rural poor in four reservoirs: two small reservoirs in the Indo-Gangetic basin, and two very large reservoirs in Africa, the Lake Nasser in the Nile Basin, and the Volta Lake in the Volta Basin.

First, the project evaluated traditional and established fish and fisheries production and management approaches in the four reservoirs. A series of fisheries enhancement tools were then developed and tested in each of the four selected reservoirs in collaboration with the main stakeholders: small-scale cage culture technology on the shore of the Lake Volta, a combination of seed stocking, and cage and pen units in the two selected reservoirs in India, and enclosures that combines stocking of preferred species with the removal of predators in three embayments (*khors*) of the Lake Nasser.

Second, a series of socio-institutional analyses was also implemented in the three basins. Those analyses did not simply confirm the importance of institutions in shaping the economic and social inter-actions occurring in fishery activities in general. They also stressed the role that those institutions play in determining which technological option(s) can be considered and adopted, and how this adoption impacts on the various socio-economic groups in the population.

The third main component of the project was a series of capacity strengthening activities aimed at supporting the other fisheries productivity interventions of the project. These capacity building interventions included a succession of eight 'capacities strengthening' and 'community consensus' workshops organized in each basins and a series of post harvest interventions on fish processing and fish trading implemented with the fishing communities involved in the project.

Substantial amount of primary data was generated through these various activities, thus improving knowledge in different domains (bio-physical and ecological attributes of the reservoirs, and economics, institutional and social dynamics of the communities living in the vicinities of the reservoirs), while a concurrent effort was made to synthesize existing secondary data.

Overall the results of those different researches stress that while the natural biophysical constraints of the reservoirs define the ecological production processes, it is the socio-economic settings that eventually shape the human production enhancement possibilities of the reservoirs. In other words, manipulation of reservoir ecosystems to improve productivity and outcomes for lower income communities is feasible, but to realize this, adaptive research needs to work closely with users to ensure that the rationale of the intervention and the technical details are fully appreciated by local stakeholders and, maybe more importantly, that research and extension come to understand the real opportunities and constraints confronted by potential investors.

EXECUTIVE SUMMARY

Background

An ever-growing number of small, medium and large reservoirs are being built in the world for irrigation or hydro-power purposes. While some fishing activities take place on these water-bodies, the productivity of their fisheries is in many cases far below the identified biological potential. Yet, fisheries and their associated activities (fish processing and fish trading) have been recognized to play a critical role in terms of food security and economic development.

Reservoirs are only semi-natural ecosystems, usually being the result of humans having transformed a river into a lake, with a sometimes poorly adapted and consequently highly dynamic aquatic fauna. The productivity from reservoir fisheries can be increased through a number of approaches combining better harvesting strategies, carefully adapted stock enhancements, and aquaculture activities. To achieve this untapped potential while securing ecosystem services such as water quality and biodiversity, a holistic approach and improved understanding involving both biological principles and stakeholder participation is necessary. The natural biophysical constraints of the reservoirs define the ecological production processes and the socio-economic settings shape the human production enhancement possibilities. By synthesizing these mechanisms into general principles and predictive indicators it should be possible to provide various options and scenarios for improved productivity that can be adapted to the local cultural and institutional settings.

Objectives of the project

The main objective of this 3.5 year project (CP34) was to increase the productivity of reservoir fisheries and provide sustainable livelihoods to the rural poor through a series of interventions in tropical reservoirs. The main project activities focused on two reservoirs in the Indo-Gangetic basin (Dahod in Madhya Pradesh, and Pahuj in Uttar Pradesh, both in India), the Lake Nasser in Egypt as part as the Nile basin, and the Volta Lake in Ghana as part as the Volta basin. For each of those sites the specific objectives of the project were:

- Objective 1: To identify, develop, and test in collaboration with the main stakeholders, fisheries enhancement tools and strategies leading to increased fish productivity and better community livelihood prospects;
- Objective 2: To improve the understanding about the overall human contexts of those reservoirs and identify potential socio-institutional obstacles to the adoption of increased fishery productivity innovations;
- Objective 3: To facilitate the implementation of these fisheries productivity interventions by improving the stakeholders' management skills and fostering their institutional capacities;

In addition to those objectives, the project encompassed an initial data inventory from a wide variety of tropical reservoirs within the three basins, and the detailed assessment of the selected reservoirs, including market evaluation and post-capture improvements.

Results – research findings

Overall, a substantial amount of primary data was generated by CP34 in various domains (bio-physical and ecological attributes of the reservoirs studied, economics, institutional and social dynamics of the communities living in the vicinities of these reservoirs) while a concurrent effort was made to synthesize existing secondary data. Through the generation of this primary and secondary information, the project greatly contributed to the body of research on reservoir fisheries.

A series of fisheries enhancement tools were developed and tested in line with the first objective of the project. Mixed results emerged.

Executive Summary CPWF Project Report

In Ghana, small-scale cage culture technology was tested on the shore of the Lake Volta. Despite the difficulties encountered, the technical feasibility of the cage culture system was demonstrated. Low yields and profits were recorded however, which raised the question of the economic viability of the technique. Despite this uncertainty, some 20 cage operations in the lower Volta River basin are now adopting and adapting the technology demonstrated by the project on the Lake.

In India, a combination of seed stocking (species composition of fish seed, direct stocking of higher value fish seed to support natural reproduction, and installation of cages to raise the required size of seed for reservoir stocking) was successfully developed in Dahod and Pahuj reservoirs. Results show a substantial change in the species composition of the reservoirs with an increase in major carps and catfishes (some of the stocked species). In Pahuj, the catch increased by 145%.

In Egypt, efforts to improve productivity in Lake Nasser are particularly constrained by government policy vis-à-vis water quality. As a result, a practical system of enclosures that combines stocking of preferred species with the removal of predators was tested in three embayments (*khors*) of the Lake. The model is yet to show tangible results.

Overall these different results show that manipulations of reservoir ecosystems to improve productivity and outcomes for lower income communities are feasible, but to realize these, adaptive research needs to work closely with users to ensure that the rationale for the intervention and the technical details are fully appreciated by local stakeholders and, maybe more importantly, that research and extension come to understand the real opportunities and constraints confronted by potential investors.

Along with these technical interventions, a series of socio-institutional analyses was also implemented in the three basins. The objective was to investigate the socio-institutional and economic dynamics of some of the different processes associated with fisheries reservoirs and to explore in particular the potential links that exist between these socio-institutional processes and the capacities of local actors to engage in technical innovations to enhance reservoir fisheries.

In India, our results suggest that a large part of the reservoir productivity is not explained by the bio-physical or ecological parameters of the reservoirs, but, rather, by the economic and institutional context of the communities, and in particular the leasing system through which different types of actors can compete to obtain the reservoirs' fishing and management rights.

In Egypt, our results show that the different types of share contracts that exist in the fishery are essential for the overall productivity of the fishery in that they allow the different actors (license owners, fishing gears owners, boat crews) who generally do not possess all the different types of capital and resources necessary to engage in the sector to combine their individual resources with other agents' resources and put them to productive use.

The Egyptian case also underlines the importance of macroeconomic policies in shaping the socio-institutional context of fisheries and, in particular, in influencing the actors' abilities to engage positively (or negatively) in the sector. In our case it demonstrates how the combination of inappropriate macro-economics policies has led to the creation of a massive black market for fresh fish.

In Lake Volta, we investigated the potential tension and social issues that are often associated with the 'privatization of the commons', following investments in fishery enhancing techniques. In our case we looked at this issue in the context of *acadjas* (brush parks), a form of fishery intensification/enhancement technique found in many fishing communities along the shore of the Lake and elsewhere in the developing world.

Finally, our last results relates to capacity building. This series of interventions arises from the recognition that one of the most constraining factors to the adoption of (technical or institutional) innovations by the poor is their limited organizational and institutional capacities. Both at individual and collective levels, the ability of poor households to engage in innovation and change

is often more limited than for the better-off households. The last objective of the project was therefore to identify and implement a series of capacity building activities. These included a succession of eight 'capacities strengthening' and 'community consensus building' workshops organized in each basins and a series of post harvest interventions on fish processing and fish trading implemented in the communities involved in the project.

Outcomes and impacts

The outcomes and impacts of the project are, like the results above, somewhat mixed. Some immediate positive outcomes were observed in the two small reservoirs in India (in the form of a direct increase in the productivity of the reservoirs and in economic returns to individual fishers and fish traders). At a higher level, the provincial state officials were convinced about the feasibility and application of the project outputs and selected another 51 reservoirs to implement an enhancement model similar to the one tested by the project.

The situation on the shores of the Lake Nasser and the Volta Lake is more ambiguous. The cage culture experiment conducted in Lake Volta has motivated an increasing number of households to engage in this activity –even though the project trial had not been as successful as it could have been. It is however too early to consider these households as evidence of a real 'take-off' in the adoption of small-scale cage aquaculture, or even to draw conclusions about the (long-term) economic viability of the activity. In particular the initial minimum investment required to establish cage culture system represents an important constraint for the poorest.

In Egypt, although a certain number of *khors*' 'owners' have expressed the wish to adopt the enclosure model tested by the project, the current experiment has yet to demonstrate increased productivity and benefits to the local fishers (or to the consumers). More methodological and technological efforts are required to master both the technique and the evaluation of its impact. More effective in terms of direct impact were the activities implemented in relation to the salted fish processing. Overall, improved management of the Lake Nasser fishery remains, however, severely constrained by current smuggling activities.

International public goods

By developing, testing and publishing results of a combination of ecological research and carefully adapted stock enhancements and aquaculture strategies adopted in three different basins and four biophysically different tropical reservoirs, the project contributes significantly to the current research on reservoirs fishery enhancement in tropical countries. Beyond the areas of direct intervention of the project, the project offers useful lessons for practitioners and/or researchers interested in similar activities in the same basins or elsewhere in tropical regions. A large part of these lessons concerns technical aspects (see below) but also some wider reflections on the general issue of water productivity in small and larger reservoirs. These lessons are embodied in three individual basin reviews produced by the project, a global synthesis document and a specific report on water productivity in fisheries.

Another area where the project contributes to IPGs is the knowledge base on socio-institutional and economic processes associated with fisheries enhancement activities. Through various analyses, we investigated several of these socio-institutional processes, including the role of leasing rights on reservoir productivity, the effect of contractual arrangements on fisher incentives and capacity to engage in reservoir fisheries, and the potential issues related to the 'privatization of the commons' associated with investments in yield intensification technology (cages, stocking, etc.). A series of publications that describe and analyze those different issues has been submitted to peer-reviewed journals.

However, the main effort of the project has been on developing and testing appropriate tools and methodologies to increase productivity of fisheries in lakes and reservoirs: enclosures in Lake Nasser embayments (*khors*), cages to raise fry for stocking Indian reservoirs, and small-scale cage

Executive Summary **CPWF Project Report**

culture in Lake Volta. The main results of these trials were documented in a series of articles submitted to peer-reviewed journals and in a series of five Technical Manuals.

Finally, a number of fish processing/conservation techniques have been developed and/or tested during the implementation of the project and are documented in this report: fish smoking ovens in Lake Volta, wood chambers for fish salting in Lake Nasser, and ice boxes for fish transportation in India.

Recommendations

- Given the general lack of understanding of biological production processes in larger (but also to some lower extent, smaller) reservoirs, there is still a need for further fundamental research on those processes.
- It is possible to manipulate, govern, and determine a natural environment, but vast opportunities still exist for increases in productivity from a purely biological point of view. The level of intensive methods should therefore be seen in relation to the spatial scale of the reservoir.
- The environmental sustainability of yield enhancement technology, especially the introduction of potentially eutrophying feeds and stocking of fish which do not naturally recruit into reservoir will depend to a large extent on the intensity and density of cages, enclosures and the invasiveness of introduced species. These impacts are easier to manage in smaller reservoirs. Larger bodies of water seem inherently less amenable to management.
- There is a need for carefully document and understand the natural production processes and their controls and limitations before endeavouring into technological solutions that may turn out to be economically or technically unaffordable for the poorest.
- The historical context and inherent scientific preconceptions that characterize research and management institutions should be acknowledged when evaluating the chosen pathways or ideas in the attempt to increase reservoir fishery productivity. Still, they should also be evaluated in a larger framework within currently available scientific knowledge and practices in order to classify these choices and help in understanding the distinction between theory and knowledge (separate beliefs and facts). In developing international programs as the current Challenge Programme, time and space should be made available to enable such evaluations.
- A close engagement with the local communities to identify the ongoing activities and developments, and gaps in the institutional knowledge, as well as a willingness to objectively test without prejudice their various adaptations seems at present to be much more rewarding in terms of increased productivity than technological solutions that require close control over all links in the chain.
- Given the importance of the socio-institutional and policy processes in influencing the overall capacities of local actors to engage/invest in technical innovation, further research and analysis of those processes is critical if one wishes to ensure a better contribution of research to the question of the productivity of reservoir fisheries.
- To increase their potential impacts, improved fish productivity projects in tropical countries should, as much as possible, include interventions that aim at increasing the capacity of fisherfolk communities in low-cost technologies and post harvest losses.
- Technological approaches to increasing productivity may have only *indirect* positive impacts on the poorest of the poor. Government logistical and technical support can increase the benefits accruing to lower income groups the overall cost of private investment in these technologies limits direct participation to less poor groups.
- Conflicts seem nearly inevitable in any system where benefits from the exploitation of common resources appear to accrue disproportionately to one group among several. Consultation and participation with local institutions and stakeholders can reduce these conflicts, but in situations of extreme poverty and heavy dependence upon natural resource exploitation for livelihoods, the extent to which privately-owned investments in common pool resources can contribute simultaneously to increased productivity *and* poverty reduction is therefore limited.

INTRODUCTION

Reservoirs are an essential component of most irrigation systems and, together with those built for flood control and power generation retain a large volume of water worldwide. The 60,000 largest reservoirs in the world – those with a volume of 10 million cubic meters or more– are estimated to cover a surface of about 400,000 km² and together hold some 6,500 km³ of water.

In addition to their role in providing water for agriculture, industrial and domestic purposes, and in power generation, most of these reservoirs also play an important role in fish production and contribute significantly to the livelihoods of communities along their shores. Yet there is widespread recognition that the fisheries potential of most of these reservoirs greatly exceeds current use, provided that environmentally and socially sustainable management systems can be developed and adopted.

The productivity or development benefit from reservoir fisheries can be increased through a number of approaches. First the yield from existing fisheries can be increased through better management measures. For example, established fishery regulations are mostly based on single-species management and associated gear restrictions, but there is increasing evidence that a diverse combination of fishing gear, resulting in an overall unselective fishing pattern on the fish community, not only maximizes the yield but also maintains the relative structure of the ecosystem and the biodiversity (Misund et al. 2002, Jul-Larsen et al. 2003). For example, on the Zambian shore of Lake Kariba, fishers using such approaches have been shown to obtain sustainable yields that are four times higher than the catch per unit area in Zimbabwe (Kolding et al. 2003a).

Second, the value of many fish catches can be increased through improvements in processing and marketing. For example in Lake Chad basin there is considerable potential to increase the value of the fishery if the harvest can be marketed in urban centers at higher prices (Neiland and Béné 2004). It is also widely recognized that in most reservoir fisheries in the developing world, there is substantial scope for improving equity through establishment of community management systems for reservoir resource use.

Building upon these improvements in the existing fishery, most reservoirs have substantial potential for fishery enhancement using a range of techniques. For example in Asia potential yields from reservoir fisheries are estimated to be 500-2000 kg/ha/year, while the use of cove culture in the water inlets to reservoirs in China brings productivity in these areas up to the level of pond aquaculture, approximately 4500-7500 kg/ha (Li 1994). In India, reservoirs yield an average of 20 kg/ha, which is far below the potential. Even a moderate increase of 100 kg/ha for small and 50 kg/ha for medium and large reservoirs can provide additional 170,000 t of fish (Sugunan 1995). Cage aquaculture may also be used to increase production. First developed in China, cage culture is now used in an increasing number of countries where it is seen as a means of increasing aquaculture potential without using scarce land resources, and as a means of compensating for loss of agricultural land underwater behind dams. The full range of enhancement technologies, including cages, has been estimated to be able to increase freshwater yields by up to 20 percent (Lorenzen et al. 2001).

By working with local fishing communities to design fisheries management systems that are adapted to the biological diversity, natural productivity, and other uses of these reservoirs, the range of fishery development options available provide a significant opportunity for increasing water productivity in many tropical river basins.

To achieve this and harness the potential of these different possibilities of enhancement, an improved understanding of the biophysical dynamics and ecology of these reservoirs is a prerequisite. However, for these enhancements to be socially beneficial, interventions need to be rooted in community-based research where the socio-economic and institutional contexts of the communities in which these enhancement activities take place are also taken into account. Indeed, experience has shown that the changes induced by the introduction of new species or the

Objectives and Results **CPWF Project Report**

productivity increase following the adoption of enhancement techniques may not only affect the ecological dynamics of the water-bodies, but also alter the socio-institutional arrangements that link the different actors involved in the enhanced fishery activities (e.g. Ahmad et al. 1998, Apu and Middendrop 1998). Mechanisms such as enclosure (i.e. privatization of the common property resources), social exclusion of one part of the community, usually the poorest, re-appropriation by the more powerful (local elite) may annul partially or even totally the potential benefits generated by an adopted enhancement program (Ali and Islam 1998 Capistrano et al. 1994). The socio-institutional changes induced by these improved productivity activities needs therefore to be anticipated, assessed and carefully managed.

The project presented in this report was aimed at addressing those different issues. Its main objective was "to increase the productivity of water and provide sustainable livelihoods to the rural poor through improved fisheries management in tropical reservoirs". For this, three basins were selected amongst the 9 Benchmark basins of the Challenge Programme, and within those specific basins a series of reservoirs were identified for study: two small-scale reservoirs in India as part of the Indo-Gangetic basin, Lake Nasser in Egypt as part of the Nile basin, and the Volta Lake in Ghana as part of the Volta basin.

PROJECT OBJECTIVES

The specific objectives of the project were:

1. To identify, develop, and test in collaboration with the main stakeholders, fisheries enhancement tools and strategies leading to increased fish productivity and better livelihood prospects in reservoirs communities;
2. To improve the understanding about the overall human contexts of those reservoirs and identify potential socio-institutional obstacles to the adoption of increased fishery productivity innovations;
3. To facilitate the implementation of these fisheries productivity interventions by improving the stakeholders' management skills and fostering their institutional capacities;
4. To compile, analyze and disseminate the knowledge, methodologies and know-how on enhanced fisheries in tropical reservoirs generated by this project in order to contribute to the improved understanding of reservoir management.

Section 1: Fisheries enhancement tools

1.1. Bio-physical and ecological dynamics of tropical reservoirs

Unlike rivers, reservoirs offer ample scope for fish yield optimization through suitable management. The sheer magnitude of the resource makes it possible to enable substantial increase in yield by even a modest improvement in productivity. In India alone 19,370 small, medium and large reservoirs exist with a total area of 315,366 ha (Sugunan, 1995). Reservoirs thus represent an important opportunity to increase productivity in inland fisheries, but to realize this potential a balance must be struck between the objectives of income generation, yield optimization and environmental issues.

As part of the first specific objective of the project, a preliminary task was to improve and/or update scientific knowledge about the bio-physical and ecological dynamics of the reservoirs in the three basins under consideration in an attempt to estimate more precisely the potential productivity. Both primary and secondary data were used. Different approaches were undertaken in the three basins, reflecting their different status and number of reservoirs.

In the Indo-Gangetic Basin, where several hundreds of reservoirs are scattered over various climate, altitude and ecological conditions, a comprehensive survey of 604 reservoirs was completed in the eight states of the basin. The survey included morphometric, physico-chemical, nutrient and biological attributes as well as socio-economic and institutional data (results regarding this second component are presented in Section 2). In the Volta Basin where the focus of the project was on the Volta Lake, bio-physical data were collected, and a community-based catch assessment conducted with the help of local fishers. Secondary (published and gray) literature was also collated. Similarly in the Nile Basin where the project focused on Lake Nasser, physical, chemical and limnological features of the lake were collected to complete the existing literature and experimental fishing were conducted to update our knowledge about the status of the main species. The sections below summarize the main results of those activities.

1.1.1. Indo-Gangetic Basin

Data collection

A performa was developed and circulated by CIFRI to collect the preliminary information on 604 reservoirs from 8 different states in the IGB. The Department of Agriculture, Animal Husbandry, Dairying and Fisheries, Government of India adopted the performa for collection of data on reservoirs and also asked the State Fisheries Departments (SFDs) to provide the information. The information collected through the survey, however, turned out to be insufficient or of poor quality in some states. Complementary surveys were organized to fill the gaps, but information on some

Objectives CPWF Project Report

important parameters is still lacking, as it was not documented initially by the SFDs or the Department of Irrigation who control reservoirs for management in states.

The data¹ was collected in different districts of eight Indian IGB states, namely, Himachal Pradesh, Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand, Rajasthan and West Bengal. The collected information was then tabulated and subjected to statistical treatment. The variables considered included the reservoir area, mean depth, reservoir age, stocking density, species stocked, yield, etc.

The main characteristics of the two case study sites (the Dahod reservoir in Madhya Pradesh and Pahuj in Uttar Pradesh) which were subsequently selected for the project are also presented below.

Results

For the purpose of fishery management, reservoirs in India are classified as small (<1000 ha), medium (1,000 to 5,000 ha) and large (>5000 ha) although, different states have varied classification, according to size wise distribution. Sugunan (1995) had estimated the total area to be 1,485,557 ha for small, 527,541 ha for medium and 1,140,268 ha for large reservoirs. Indo-Gangetic basin has 1.16 m ha area or 36.8% of total reservoirs in the country (Table 1.1.). Small reservoirs cover the largest proportion (40.6%) followed by large (33%) and medium (26.4%). Small reservoirs are also the most numerous (>566) followed by medium ones (>80) while only 26 reservoirs are large. Most of the reservoirs in the small size group lie below 500 ha while many of the reservoirs in medium category are within 1000-2000 ha.

Table 1.1. Distribution (in %) of the studied reservoirs according to area across Indian IGB states.

Area (ha)	States								IGB-India
	Uttar Pradesh	Punjab	Himachal Pradesh	Haryana	Rajasthan	Bihar	Jharkhand	West Bengal	
<100	5.56	87.50		100	49.06	25	4.76	16.67	42.76
100-250	27.78	12.50	40		24.06	37.50	57.14		26.15
250-500	27.78		20		8.96	12.50	23.81	16.67	11.31
500-1000	22.22		40		9.43		4.76		9.54
>1000	16.67				8.49	25	9.52	66.67	10.25

The claim that Indo-Gangetic reservoirs should have a much higher production of fish than they have is mainly based on limnological arguments. In particular, relying on hydro-chemical factors and primary productivity, the large reservoirs in India are thought to have a productive potential of 65-190 kg/ha, the medium reservoirs 145-215 kg/ha and small reservoirs 285-545 kg/ha per year.

As with many natural lakes, biophysical factors that determine productivity in reservoirs can be summed up as morphometric (area, depth, shoreline), edaphic, physico-chemical and climatic. A number of morphometric indexes: the Shoreline development index (SDI), the Volume Development Index (VDI), the Catchment to Reservoir Area and the Flushing Rate have been proposed to relate these factors to potential productivity. For other key variables, such as water level fluctuations and area of shoreline inundation between low and high water levels, both of which are known to be dynamic predictors of fish productivity and yields, data is lacking.

Morphometric characteristics

Mean depth (volume/area) is considered to be the most important parameter indicative of the extent of the euphotic/littoral zone (Hayes 1957). Below 18 m, reservoirs sometimes serve as a

¹ Primary data available from: CIFRI (2006) Inventory of reservoirs in the Indian Indo-Gangetic Basin. Project report for the Challenge Programme CP34 "Improved fisheries productivity and management in tropical reservoirs" Central Inland Fisheries Research Institute, (ICAR), Barrackpore, Kolkatta, India, 33 p.

'nutrient sink' (Rawson 1955) as seen in some deep reservoirs of India. Hydel reservoirs on the mountain slopes with steep basin walls for instance are considered 'biological deserts'. Depth is not always a constraint for production, however, with deep reservoirs such as Bargi (14 m) in Madhya Pradesh, Chamera (43.5 m) and Govindsagar (55.0 m) in Himachal Pradesh, Rihand (22.8 ha) in Uttar Pradesh, Badua (14.5 ha) in Bihar being productive due to other favorable factors. Most of the Indo-Gangetic basin reservoirs in the small and medium size groups have a low mean depth (4-7 m) (Table 1.2) and are expected to have a high potential for fish production.

Table 1.2. Morphometric and hydrological features of Indo-Gangetic basin reservoirs.

Indo-Gangetic basin States	Reservoirs area (ha)	Number	Mean depth (m)	Elevation (m amsl)	Catchment Area (km ²)	Volume Dev Index	Total Inflow (10 ⁶ m ³)
Jammu & Kashmir			25				
Himachal Pradesh	900-15000	3	20- 55	440-899	4725-56980		
Punjab	46-280		4-10		6.1-56.1		
Haryana		4	3.4-5.0		11.4-11.9		
Rajasthan	165-1554	423	1.7-7.7		35-27840		
Uttar Pradesh	17.5-30149	66	3-22.8	119-268	32.4-13344		
Madhya Pradesh	77-66000	32	3.4-14.0	348-488	8.3-23025	0.5-1.7	27-7800
Bihar & Jharkhand	21-3733	125+	5.2-14.6		29-6120	0.7-1.4	
West Bengal		6	3.2-11.0				

The Shore development index ($S/2\sqrt{\pi A}$ where, S = shoreline length, A = area of the reservoir) indicates the degree of irregularity of shoreline. High values of this index are indicative of higher productivity. Reservoirs with a dendritic shoreline, (such as Lake Nasser or Lake Volta) with many sheltered bays and coves, and with extensive littoral areas are likely to be more productive, while many of the IGB reservoirs have fewer branches and so might be considered less so.

The Volume Development Index ($VDI = 3 \times \text{mean depth}/\text{max depth}$) denotes the depth of the basin in relation to the nature of basin wall. If the value is >1 , the basin is cup shaped; <1 the basin is saucer shaped. Deep reservoirs with less littoral area have a VDI of >1 and are generally less productive. In contrast, the VDI of many of the small and medium reservoirs of Madhya Pradesh, Rajasthan, Uttar Pradesh, Punjab, Bihar and Arkhand is <1 and moderately productive.

Relative Lake Level Fluctuation

In general, system productivity increases with increased relative variability of water level. The index of Relative Lake Level Fluctuation (RLLF) defined as the relation between mean lake level amplitude and mean depth is an expression which attempts to reflect those dynamics (Kolding and van Zwieten, 2006). For a number of the reservoirs surveyed, average annual fluctuations are known and have been used to investigate relations with productivity and effort (Fig.1.1).

Though a significant relation between RLLFs and fish productivity was found this result depended entirely on the outlier of the highly productive and highly variable Gulariya Reservoir. This is a small reservoir in Uttar Pradesh that covers 300 ha when full, shrinks to 6.7 ha during summer and dries up completely during extreme years. When this data point was removed the relation between productivity and RLLF became non-significant.

Objectives CPWF Project Report

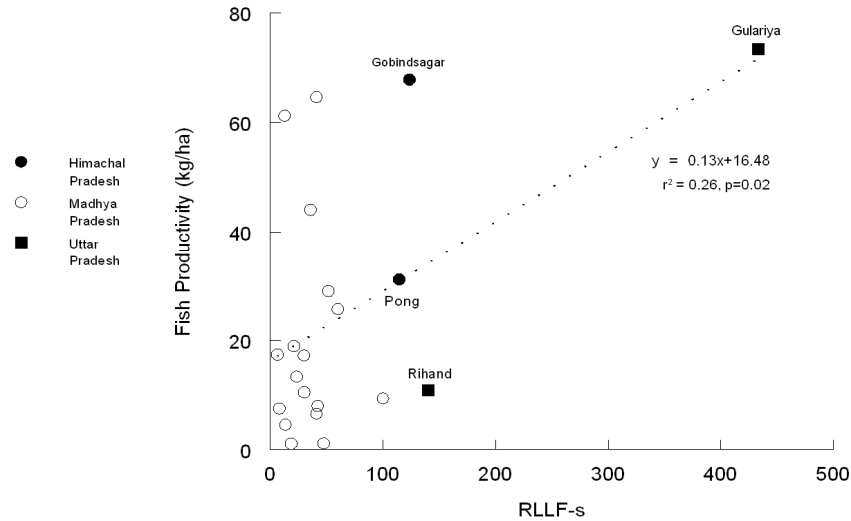


Fig.1.1. Relation between fish productivity and index of Relative Lake Level Fluctuation (RLLFs = % average annual drawdown/mean depth) in 21 lakes of the Indo-Gangetic Basin.

Case studies

Under CP34, detailed primary data was generated on two reservoirs selected (Fig.1.2). Both fall under small category reservoirs. The data generated on different biophysical and fishery aspects gives the basic idea about their production functions. Based on the information generated on these reservoirs, appropriate enhancement strategy was planned and executed at both sites during the project period (see section 1.2 below).

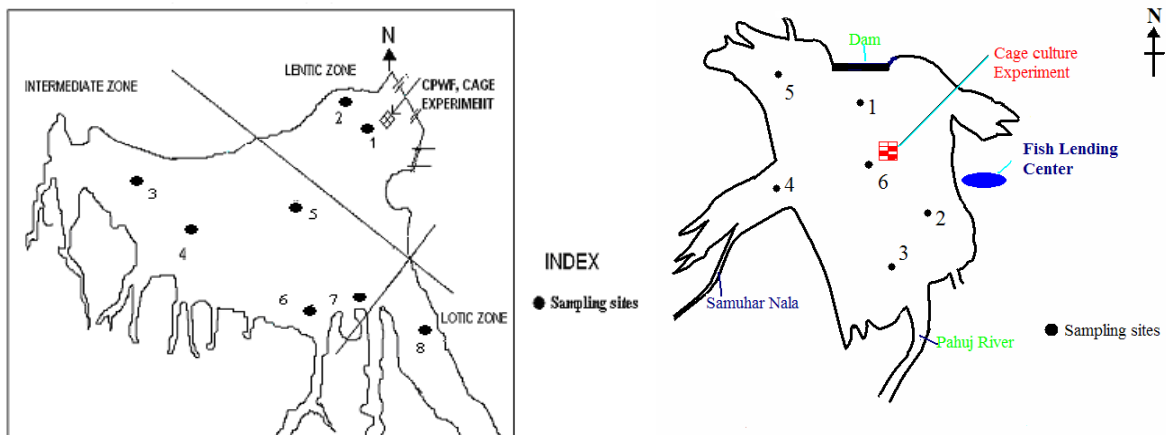


Fig.1.2. Maps of Dahod reservoir (left) and Pahuj reservoir (right)

Biophysical features:

In Dahod, the annual water level fluctuation is quite significant. During pre-monsoon the minimum water depth can drop as low as 2.5 m. Apart from natural water level changes, the water discharge is also controlled by the authorities of the irrigation department. In Pahuj, the water level fluctuation in this reservoir was less in comparison to Dahod. During post-monsoon, especially in winter, the water depth does not fall below 3.0 m, while the depth remained > 5.0 m during most of the year. This adequate water depth appeared to be very much helpful for congenial growth of fish stocks. The minimum water level changes in this reservoir had a positive impact on overall productivity of the reservoir.

In Dahod, the data on main water quality parameters viz., pH (7.2-8.5), dissolved oxygen (5.5-8.5 ppm) total alkalinity (35-90 ppm), hardness (30-60 ppm), suggest good conditions for fishery productivity. These parameters recorded seasonal variations strongly related with monsoon dilution and temperature seasonality as well. The nutrient ranges vary significantly. The concentrations are very low in some period, probably being used at a faster pace by some food chain elements in the ecosystem.

In Pahuj, the data on main water quality parameters viz., pH (7.5-8.6), dissolved oxygen (7-10.6ppm), total alkalinity (100-170ppm), total hardness (80-170ppm) indicate that concentrations of major parameters are on a higher side, which is very congenial for sustaining good fishery. The higher oxygen concentration in some months is due to myxophyceae bloom observed in the reservoir. The parameters do record seasonal variations strongly related with monsoon inflows and temperature seasonality. The nutrients ranges viz., nitrates (<50 - >300 ppb) and phosphate (<50-350 ppb) are moderate to support the food chain. They also register seasonality with peaks during post-monsoon period. The concentrations during certain months are very low.

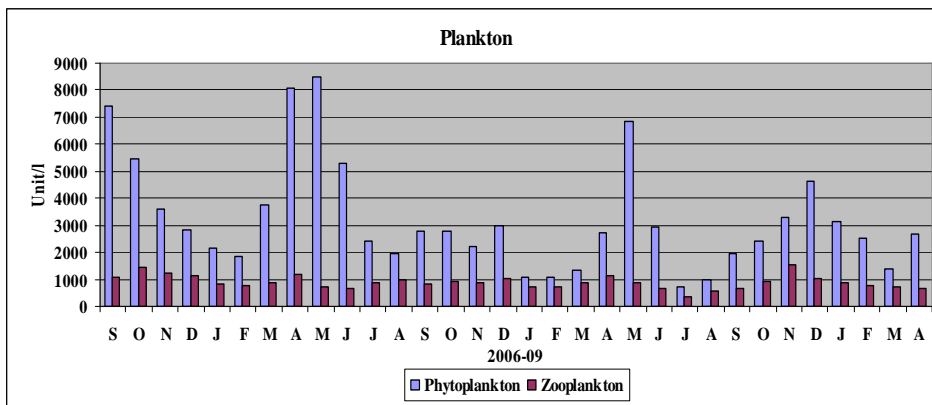
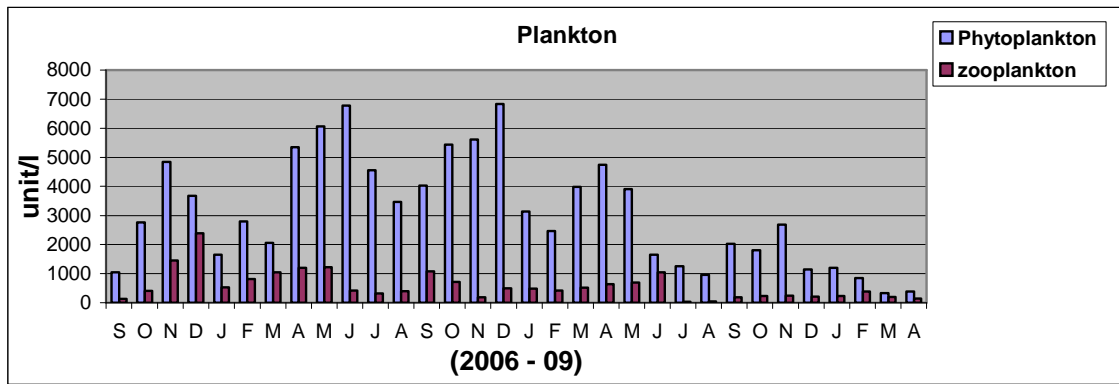


Fig.1.3. Planktonic population in Dahod (top) and Pahuj (bottom).

Plankton population:

In Dahod, the total plankton ranges between 513-7321 units/l, in which zooplankton represents between 100 to 1200 units/l. Phytoplankton is dominated by the members of myxophyceae and bacillariophyceae while chlorophyceae had marginal contribution. There was a marked seasonality among populations but usually summer and winter peaks were encountered (Fig.1.3). The zooplankton population is mostly dominated by the members of protozoa and rotifers with peaks recorded during the post-monsoon period. The members of copepods also contribute to the food chain with a marginal cladocera population as well. The seasonal trend among different groups is well defined.

Objectives CPWF Project Report

In Pahuj, the total plankton population ranged between 1088 to 9266 units/l, in which zooplankton density was in the range of 450-1300 units/l. The phytoplankton populations were well represented by different groups recording main summer peak and a minor peak during winter. The peaks were contributed by the members of myxophyceae. In comparison the bacillariophyceae remain uniform but occasional significant population of chlorophyceae were also recorded. The population composition indicates marginal symptoms of eutrophication. But it contributes to the primary production potential of the system (Fig.1.3). The species composition of zooplankton indicates dominance of cladocerns and rotifers. Very insignificant populations of protozoans were recorded. The peak densities were recorded during post-monsoon when the general water temperature is low.

Primary production trends in Dahod and Pajuj:

The data generated and depicted in Fig.1.4 indicate that during the winter months primary production per unit drops but registers major and minor peaks during pre-monsoon period. This may be related with availability of more nutrients, active plankton population coupled with longer day length and favorable temperature. While analysing the primary production recorded for Dahod, it is observed that the lower production value is $200 \text{ mg C m}^{-2} \text{ h}^{-1}$.

In contrast in Pahuj the value does not drop below $400 \text{ mg C m}^{-2} \text{ h}^{-1}$. The higher production values in case of Pahuj is above $1200 \text{ mg C m}^{-2} \text{ h}^{-1}$ with a peak of $1800 \text{ mg C m}^{-2} \text{ h}^{-1}$ while in Dahod the higher production of $450 \text{ mg C m}^{-2} \text{ h}^{-1}$ with peak record of $750 \text{ mg C m}^{-2} \text{ h}^{-1}$. This clearly indicates that Pahuj reservoir has significantly higher production potential in comparison to Dahod. This does reflect on variability in fish production from the respective reservoirs (see below).

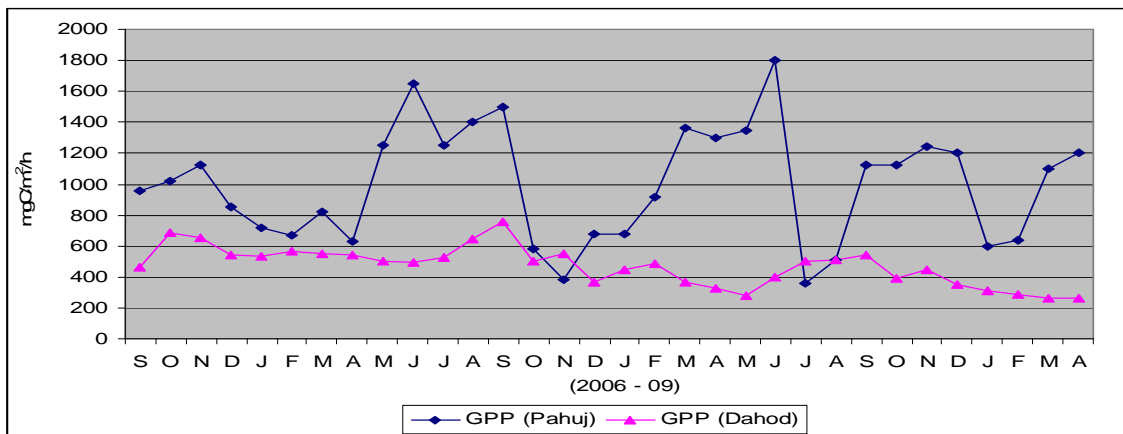


Fig.1.4. Primary production trends in Dahod and Pajuj reservoirs

Comparison of Dahod and Pahuj reservoirs:

The tabulated comparison of two ecosystems (Table 1.3) indicate that while located in the same basin but different catchments, the patterns of water level fluctuations and existing anthropogenic situation of the two reservoirs result in variability in key biophysical parameters, which strongly impinges on the overall production potential of the ecosystems.

Fishery status:

In Dahod reservoir, a fixed quota has been imposed by the SFD. The data reveals (Table 1.4) that the quota has not been achieved during the last 10 years prior to the project (1995-2004). Through the years of random stocking by the SFD the percent contribution of Indian major carps registered an increase from 8.74% in 1995-96 to 26.24% in 2003-04 with a major contribution from *Labeo rohita*. To harness the potential of this reservoir an appropriate shift towards scientific management is required.

In Pahuj reservoir where no fixed quota system has been imposed Table 1.5 indicates that the production has recorded varied peaks and lows. The reservoir was not managed as per any sustained plan but the potential exists to enhance its fish production. The data further reveals that during last ten years the percentage contribution of Indian major carps increased from almost zero to 27%; minor carps from 2% to 22.8%; catfishes from nothing to 11.37% while minnows dropped from 96 to 38.8%. The management approach in this system would be to bio-manipulate the stocks to raise the contribution of Indian major carps to about 50% and leaving remaining 50% for minor carps, catfishes and minnows.

Table 1.3. Comparative account of the project’s two case studies’ reservoirs

Parameters	Dahod reservoir	Pahuj reservoir
Area (ha)	460	480
Water level fluctuation	Very high	Very less
Year of construction	1958	1909
Organic loading	Minimal	High
Purpose	Irrigation	Irrigation
Volume FRL 10 ⁶ xm ³	27.75	18.25
Water quality		
Water temp (°C)	20-31 (26.7)	14-36 (26.33)
Water transparency (cm)	42-159(106)	30-376 (137)
Water reaction (pH)	7.31-8.40 (7.93)	7.24-8.75 (7.82)
Sp. Conductance (us/cm)	87-189 (153)	220-680 (306)
Total alkalinity (ppm)	33-80 (59)	98-176 (138)
Total hardness (ppm)	31-61 (48)	87-174 (118)
Calcium (ppm)	9.36-18.43 914.02)	19.20-46.49 (32.54)
Chloride (ppm)	7.10-17.04	25-56-88.80 (46.05)
Nitrate-N (ppb)	Trace-324 (93)	Trace-480 (130)
Phosphate-P (ppb)	Trace-276 (74)	Tr-390 (128)
Silicate-Si (ppm)	3.26-12.23 (5.90)	2-4-8-4 (4.9)
Sediment quality		
Sand (%)	>85	>70
Organic carbon (%)	Profundal (1.88) Littoral (2.8)	Profundal (3.0) Littoral (4.8)
C/N ratio	Profundal (20) Littoral (30)	Profundal (22) Littoral (42)
GPP (mgC/m ² /h)	260-750 (450)	400-1800 (1000)
Phytoplankton	Myxophyceae dominated, in 2006 but dominance of Bacillariophyceae, in 07-09	Myxophyceae dominant.
Total Plankton (u/l)	513-7321 (3680)	1088-9266 (4135)
Biodiversity		
Plankton (phyto & zooplankton)	102 species	98 species
Macrobenthos	32 species	12 species
Macrophyte	23	33
Macrophyte coverage (%)	5-35 (20)	10-40 (27)
Fish species	35	41

Table 1.4. Fish catch composition at Dahod reservoir during pre-project years

Year	Target Production	C. catla	L. rohita	C. mrigala	L. calbasu	Total carp	Total Local Major	Total Local Minor	Total Fish Production
1995 - 1996	17.8	0.17 (1.14)	0.78 (5.07)	0.22 (1.44)	0.17 (1.09)	1.34 (8.74)	4.44 (28.98)	9.54 (62.28)	15.32 (100.00)
1996 -	16.5	0.12	0.88	0.06	0.10	1.16	2.93	8.52	12.61

Objectives CPWF Project Report

1997		(0.98)	(6.98)	(0.46)	(0.82)	(9.23)	(23.23)	(67.54)	(100.00)
1997 - 1998	16.5	0.09 (0.54)	1.33 (8.09)	0.61 (3.67)	0.25 (1.54)	2.28 (13.84)	2.99 (18.14)	11.21 (68.02)	16.48 (100.00)
1998 - 1999	16.5	1.52 (9.53)	1.70 (10.63)	0.07 (0.45)	0.37 (2.30)	3.65 (22.90)	5.79 (36.29)	6.51 (40.81)	15.95 (100.00)
1999 - 2000	16.5	1.44 (9.26)	1.24 (8.02)	0.11 (0.68)	0.45 (2.92)	3.24 (20.88)	5.82 (37.57)	6.44 (41.55)	15.50 (100.00)
2000 - 2001	16.5	0.57 (3.58)	4.28 (26.95)	0.17 (1.05)	0.42 (2.65)	5.44 (34.24)	6.10 (38.42)	4.34 (27.34)	15.88 (100.00)
2001 - 2002	16.5	0.65 (4.78)	3.00 (22.07)	0.32 (2.36)	0.09 (0.66)	4.06 (29.88)	4.96 (36.50)	4.57 (33.62)	13.59 (100.00)
2002 - 2003	16.5	0.73 (5.25)	2.25 (16.31)	0.40 (2.89)	0.05 (0.33)	3.42 (24.78)	5.02 (36.31)	5.38 (38.91)	13.82 (100.00)
2003 - 2004	18.0	0.94 (6.68)	2.12 (15.10)	0.52 (3.69)	0.11 (0.76)	3.68 (26.24)	4.16 (29.69)	6.18 (44.07)	14.03 (100.00)

Figures in parentheses represent the percent of total

Table 1.5. Fish catch composition at Pahuj reservoir during pre-project years

Year	<i>C. catla</i>	<i>L. rohita</i>	<i>C. mrigala</i>	<i>C. idella</i>	Total carp	Minor carp	Catfish	Minnows	Total Production
1995-1996	0.03 (0.22)	0.02 (0.15)	0.01 (0.07)		0.06 (0.44)	0.27 (2.00)	0.13 (0.97)	13.03 (96.59)	13.49 (100.00)
1996-1997	0.87 (2.89)	0.76 (2.52)	0.54 (1.79)		2.17 (7.20)	3.99 (13.24)	2.00 (6.64)	21.98 (72.93)	30.14 (100.00)
1997-1998	11.29 (15.28)	12.90 (17.46)	8.06 (10.91)		32.25 (43.65)	4.56 (6.17)	2.28 (3.08)	34.80 (47.10)	73.89 (100.00)
1998-1999	6.80 (11.35)	5.95 (9.93)	4.25 (7.09)		17.00 (28.37)	10.22 (17.05)	5.11 (8.53)	27.60 (46.05)	59.93 (100.00)
1999-2000	1.10 (1.94)	2.19 (3.85)	0.55 (0.97)	1.64 (2.89)	5.48 (9.64)	9.43 (16.59)	4.71 (8.29)	37.21 (65.48)	56.83 (100.00)
2000-2001	3.90 (8.74)	1.95 (4.37)	1.95 (4.37)	1.95 (4.37)	9.75 (21.85)	5.88 (13.17)	2.94 (6.59)	26.06 (58.39)	44.63 (100.00)
2001-2002	4.65 (9.42)	3.10 (6.28)	3.10 (6.28)	4.65 (9.42)	15.50 (31.41)	7.40 (15.00)	3.70 (7.50)	22.74 (46.09)	49.34 (100.00)
2002-2003	2.77 (6.63)	2.42 (5.80)	2.88 (6.90)	3.46 (8.29)	11.53 (27.61)	9.02 (21.60)	4.51 (10.80)	16.70 (39.99)	41.76 (100.00)
2003-2004	2.05 (13.48)	0.62 (4.08)	1.44 (9.47)		4.11 (27.02)	3.47 (22.82)	1.73 (11.37)	5.90 (38.79)	15.21 (100.00)

Figures in parentheses represent the percent of total

Discussion

Fish production from the Indian states located in the Indo-Gangetic Basin has increased from 0.92 million tonnes to 2.08 million tonnes during the past 13 years, passing from 24% in 1990 to about 33% of total Indian fish production in 2003. The state of West Bengal is responsible for over 56% of production in the basin followed by Bihar and Uttar Pradesh. The highest percentage growth of fish production was seen in the state of Punjab where it reached 83 thousand tonnes in 2003 from 11 thousand tonnes in 1990. For most of the basin states fish production has increased over the 13 years examined (1990-2003).

Despite these trends, the productivity of Indo-Gangetic Basin reservoirs (expressed as fish yield per hectare) remains very low and the reservoirs are usually considered under-exploited with an average fish yield of only 16 kg/ha. Small reservoirs produce an average of 29 kg/ha while medium and large reservoirs yield 13 and 9 kg/ha, respectively (Table 1.6).

Table 1.6. Fish yield in reservoirs of five out of 12 Indo-Gangetic Basin States.

State	Yield (kg/ha)			
	Small	Medium	Large	Total
Madhya Pradesh	47.26	12.02	14.53	13.68
Bihar	3.91	1.90	0.11	0.05
Uttar Pradesh	14.60	7.17	1.07	4.68
Rajasthan	46.43	24.47	5.30	24.89
Himachal Pradesh	---	---	35.55	35.55
Total for Indo-Gangetic basin states	29.75	12.80	9.23	18.32
Total India	49.90	12.30	11.43	20.13

Modified from Sinha and Katiha (2002)

The fish productivity of most of the Indo-Gangetic basin reservoirs is low compared to the overall average for the country, except for medium reservoirs, where it is marginally higher. Within the Basin, fish yield is highest in the state of Himachal Pradesh followed by Rajasthan and Madhya Pradesh (Table 1.7). Considering their existing and potential productivity, the reservoirs within the IBG seem to have a very high scope for increasing fish yields.

Table 1.7. Fish production potential and actual fish yield in selected Indo-Gangetic Basin reservoirs.

Indo-Gangetic basin States	Fish production potential (kg/ha/y)	Actual fish yield (kg/ha/y)
Jammu & Kashmir	60	15-25
Himachal Pradesh	56	25
Punjab	57-100	14-70
Haryana	153-360	80-100
Rajasthan	178-478	41-365
Uttar Pradesh	85-127	5-14
Madhya Pradesh	70-545	18-63
Bihar & Jharkhand	80-325	2-8
West Bengal	75-300	15-60

More globally, the average productivity of all Indian reservoirs appears to be relatively low, when compared to fisheries that have developed in lakes and (small) reservoirs elsewhere in the world. In African lakes and reservoirs, yields of up to 329 kg ha⁻¹year⁻¹ are reached; in Latin America and the Caribbean reported yields are up to 125 kg ha⁻¹ year⁻¹ while in Asia, yields reach up to 650 kg ha⁻¹ year⁻¹ (FAO 2002). Note however that, as these are lakes of often wildly different in terms of geomorphology and exploitation, such comparisons should be made with cautious (see below section 1.1.4).

The 98 Indo-Gangetic reservoirs reviewed by Sugunan (1995) have an average productivity of 66.5 kg/ha. As the distribution is highly skewed (Fig.1.5), a better descriptor of the distribution would be the median or (4.2 kg/ha) or the geometric mean (5.2 kg/ha)². Over the whole of Indian reservoirs with their average yield of 20 kg ha⁻¹, this productivity seems far below the potential. Even a moderate increase of 100 kg ha⁻¹ for small and 50 kg.ha⁻¹ for medium and large reservoirs could provide an additional 170,000 t of fish in the sub-continent (Sugunan 1995).

² Note that those reservoirs were mainly medium and large reservoirs, therefore characterized by relatively low productivity compared to the 604 reservoirs reviewed above.

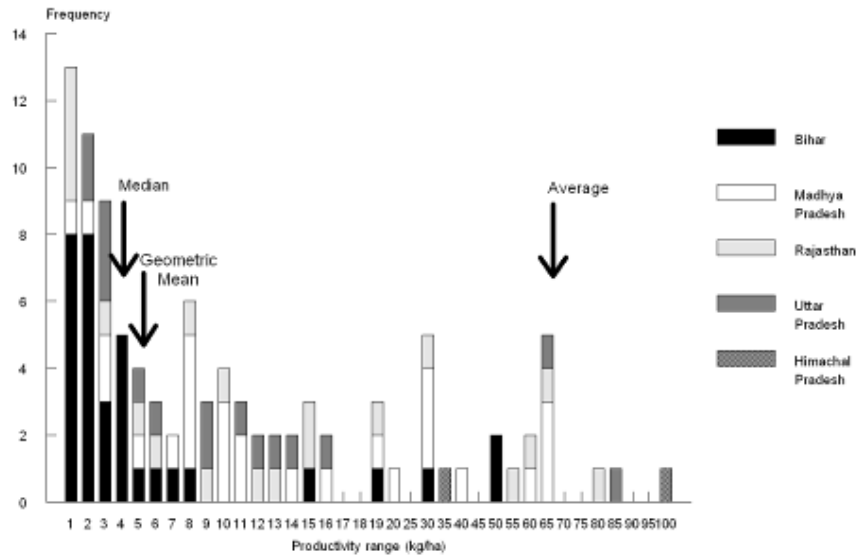


Fig.1.5. Distribution of productivity in 98 Indo-Gangetic reservoirs (source Sugunan 1995).

1.1.2. Volta Basin

Methods

Bio-Physical Studies

The Volta Lake is divided into eight segments referred to as strata, based mainly on ecological consideration (Fig. 1.6). For the CP34 activities, a station was established in Stratum II at Dzemeni (lacustrine), Stratum III at Kpando (lacustrine) and Stratum VII at Yeji (riverine). A fourth station was located on a smaller Volta reservoir below the Volta Lake at Kpong.

Methods used in studies on bio-physical characteristics are presented in Table 1.8. Selected water quality parameters including Temperature, Transparency, Nitrite – N, Nitrate – N, Ammonia – N, Phosphate – P and Dissolved Oxygen were obtained from water samples taken bimonthly initially and later quarterly at various depths 100 m and 500 m from the shore and analyzed according to Standard Methods (APHA, 1998). Data in the current study were compared with that available for previous studies.

Fish Catch Assessment

Stock assessment was undertaken using the 'fisher participatory approach' developed in Zambia (Ticheler *et al.*, 1988; Kolding *et al.*, 2003b). Five fisher groups, each comprising three members were formed to record the fish catches in two fishing days per week. The fishing gears deployed by the participating fishers in the study area were gillnets, net traps, basket traps and *acadjas*. In addition, experimental gillnets (a battery of 5 different mesh sizes of gillnets – 15.0 mm, 20.0, 25.0, 30.0 and 40.0 mm) were also deployed. Fishes caught were individually identified based on keys of Paugy *et al.* (2003, Vol. I & II), Levêque *et al.* (1988) and Dankwa *et al.* (1999). Data of catch recordings were compiled on monthly basis in Excel and exported into PasGear for analysis.

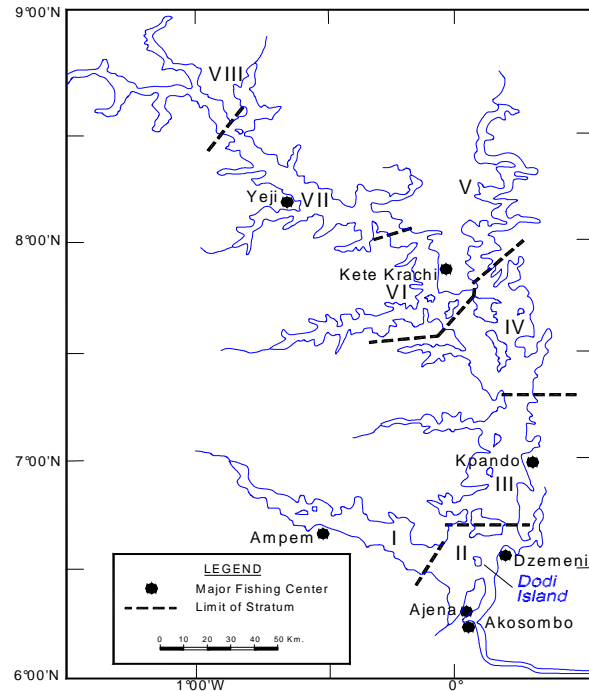


Fig.1.6. Map of the Volta Lake showing the various strata and the study areas.

Table 1.8. Comparison of water parameters from previous studies and the current one.

Water Parameter	Previous Studies	Current Study
Temperature	¹ 1964-1967; 26.4-31.5 °C	30 °C
Dissolved Oxygen	² 1969-1997; 5.2-8.1 mg l ⁻¹	5.0-8.0 mg l ⁻¹
Transparency	³ 2005; 8.1 mg l ⁻¹	Yeji 20-125 cm
	⁴ 1968-1970; 134 cm	
Nitrite-N	⁵ 1990-1995; 50 cm	0.007-0.029 mg l ⁻¹
	³ 2005; 0.05 mg l ⁻¹	
Nitrate-N	³ 2005; 0.51-0.82 mg l ⁻¹	0.29-1.7 mg l ⁻¹
Ammonia-N	⁸ 1990; 0.01 mg l ⁻¹	0.26-1.3 mg l ⁻¹
Orthophosphate-P	³ 2005; 0.34-0.5 mg l ⁻¹	0.91-0.30 mg l ⁻¹
Primary Productivity	⁶ 1964-1970; 0.8-5.2 g C m ³ 24hr ⁻¹	Not measured
	⁷ 1990; 0.2-1.35 g C m ³ 24hr ⁻¹	

Sources: ¹Lawson et al., (1969); ² Biswass, (1969); ³ Ofori-Danson & Ntow, (2005); ⁴ FAO, (1971); ⁵ Ntow, (2003); ⁶ Viner, (1969); ⁷ Antwi, (1990)

Results

Bio-physical parameters

Summarized in Table 1.8 are the results of parameters obtained in the current study compared to previous studies. Temperature profiles from surface to 8.0 m depth at the four stations showed that very narrow differences (1.0–1.5 ° C) existed between 0.0 and 8.0 m depth at all the stations. Dissolved Oxygen (DO) concentrations exhibited a decrease of about 0.25 mg l⁻¹ per meter drop at almost all stations from 0.0 to 8.0 m depth, while mean DO was about 6.8 mg l⁻¹. Conductivity of the lake ranged from 51.1 to 83.3 μs cm⁻¹. Transparency varied from station to station. Generally, higher values (200-325 cm) were recorded at Kpong, below the lake and lowest at Yeji (about 20-125cm) but predominantly below 50 cm through a year. Values for nutrients measured are considered generally low and, though not very different from what has been reported in previous studies, N and p were somewhat higher while transparency showed a dramatic decrease over time.

Objectives CPWF Project Report

Fish Catch Assessment:

The main fishing gears used by local fishers were monofilament gillnets of various mesh sizes (GN), medium basket traps (MBT), small net traps (SNT), and big net traps (BNT). Length frequency distribution of all species caught from all the gears is shown on Fig.1.7. The mean length of fishes caught in *acadjas* was about 29 cm compared to 20 cm from traps and 15-75 cm from gillnets.

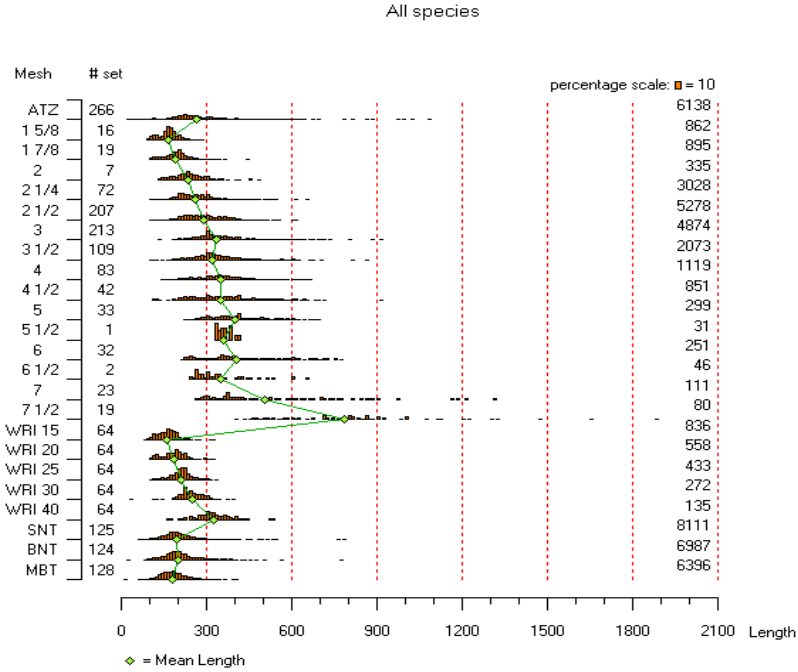


Fig.1.7. Length distribution of all species in catch of all gears deployed in Stratum II of the Volta Lake, during March 2007-June 2008. ATZ = *Acadja*, 1 5/8 to 7 1/2 are mesh sizes (inches) of stationary gillnets from commercial fisheries, WRI = experimental gillnets 15 – 40 mm mesh, SNT = small net trap, BNT = big net trap, MBT = medium basket trap

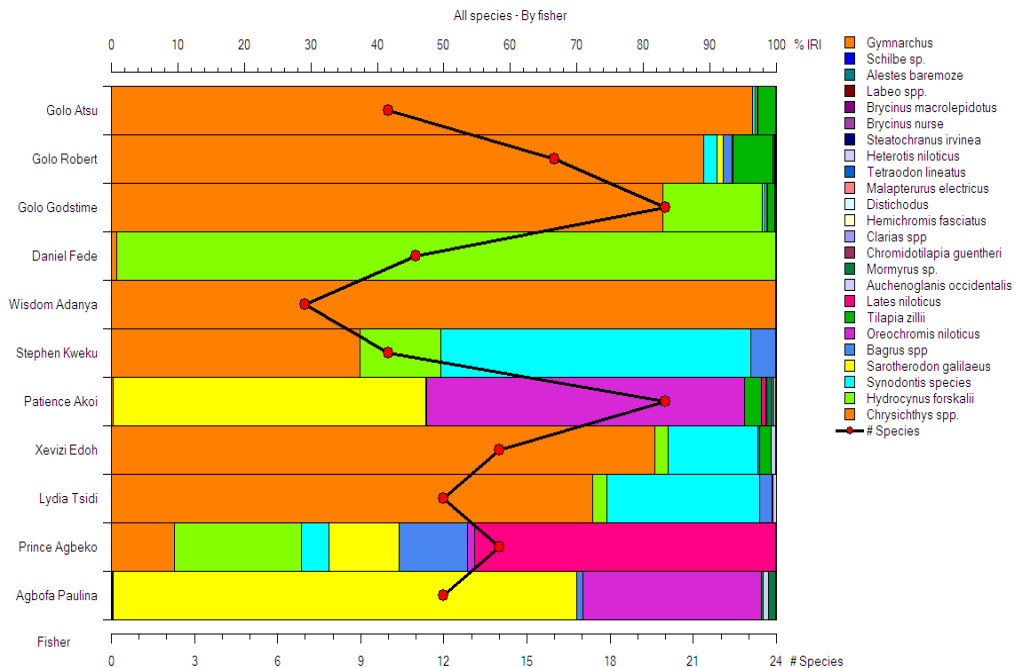


Fig.1.8. Catch composition of each fisher employed in the study during the period March 2007 to June 2008.

Fish catch composition per gear (Fig.1.8) indicates that fish caught by gillnets (mesh sizes 2.5 and 3.0 inch) was predominantly *Hydrocynus* spp.; basket traps caught almost exclusively *Chrysichthys* spp. Catches by net trap were generally more diverse compared to gill nets or basket traps. Finally, harvests from the local brush park, *acadja* were about 100% tilapias (mostly *Sarotherodon galilaeus* and *Oreochromis niloticus*).

Total catch from all gears deployed in the study (Fig.1.9) consisted of 32 species belonging to 21 genera. However, about 95% by number and 84% by weight of the catch were made up by five fish genera.

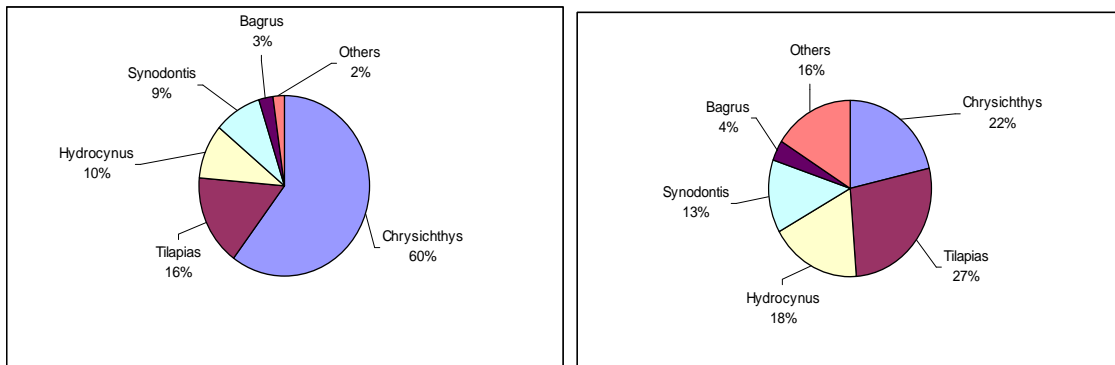


Fig.1.9. Overall fish catch composition (left=number; right=weight) from March 2007 to June 2008.

Changes in catch by species from gears deployed during the study period are presented in Fig.1.10. A larger number of species was caught in March to June 2008 compared to similar period in 2007. A similar pattern was also shown by the individual gear catches.

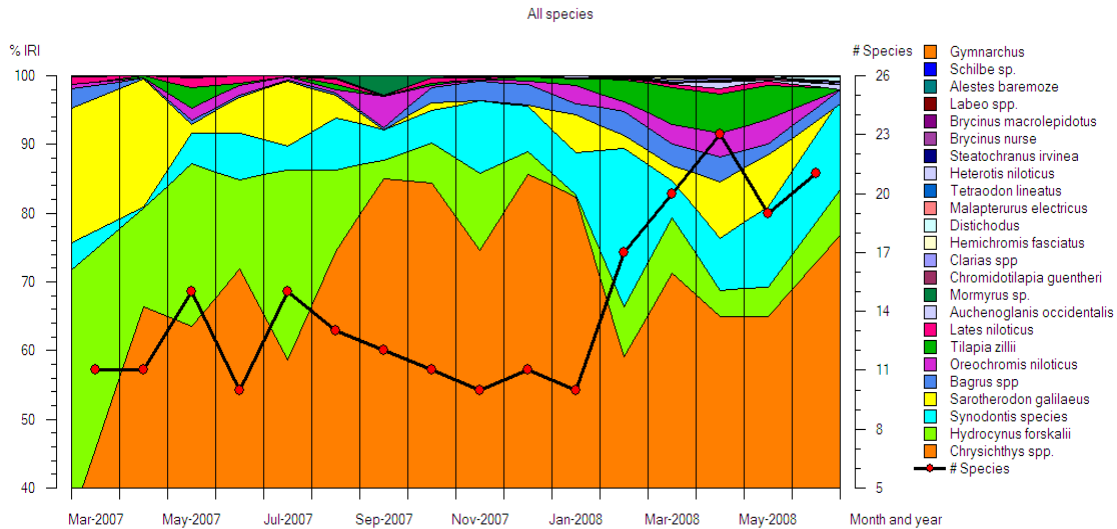


Fig.1.10. Changes in fish species composition from all fishing gears employed in the study from March 2007 to June 2008.

There was a general decreasing trend in catch from all the gears during the study period (Fig.1.11). The Figure also shows that decline in catch was inversely related to lake level changes.

Objectives CPWF Project Report

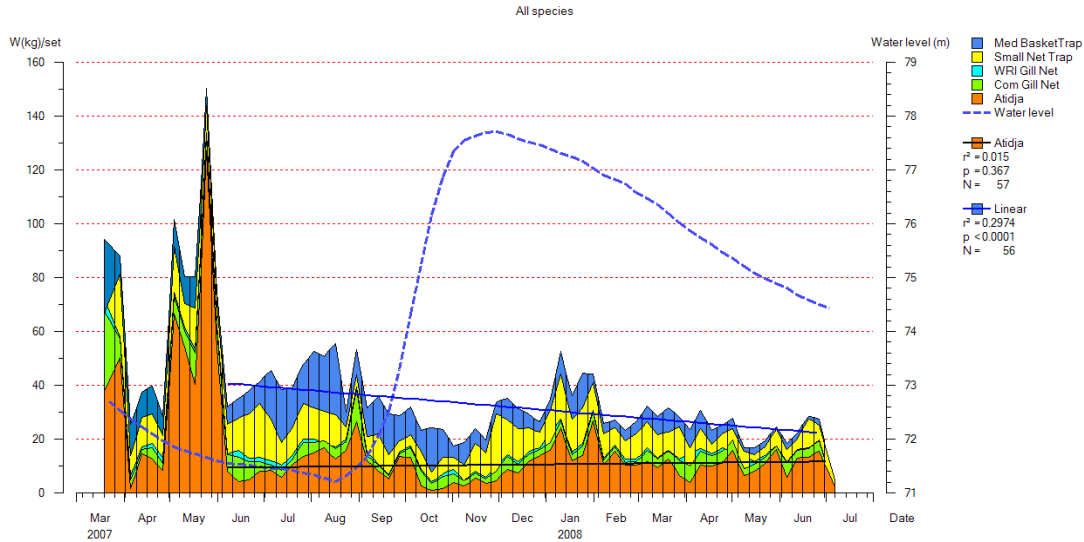


Fig.1.11. Standardized weekly CPUE of the different commercial gear categories sampled in the study for all species from March 2007 to June 2008.

Fig. 1.12. shows average catch (wt) per day by fishing gears deployed which indicates that relative catch efficiency (CPUE) of the various gears could be represented as follows: Medium Basket Traps > Net Traps > Big Meshed gill Nets > *Acadja* > Small Gill Nets.

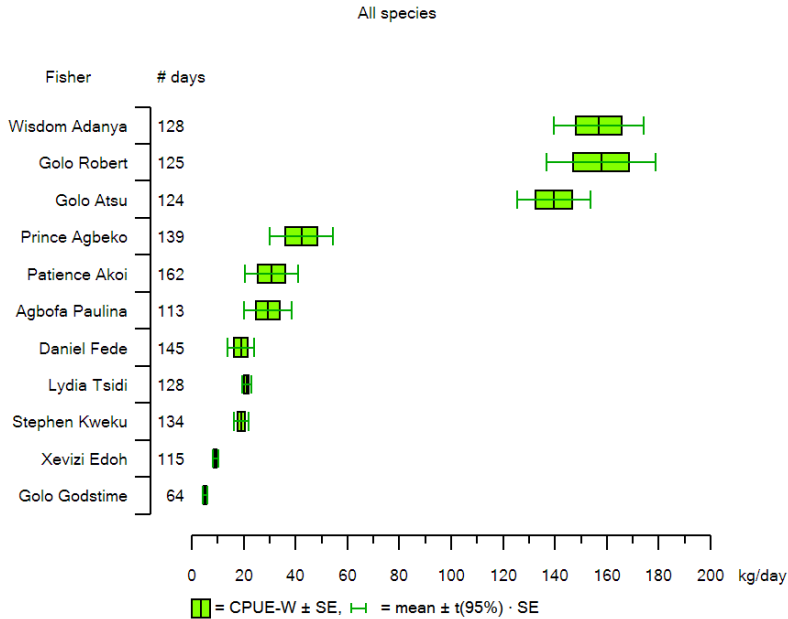


Fig.1.12. Total number of days fished over 15 months and average catch per fishing day (kg/day) for the 11 fishers engaged in the sampling scheme.

The above information complements the daily catch estimate for the various gears used in the study in Table 1.9. Limited information was available for the *acadja*'s to construct this table. On the average 3 *acadja*'s are harvested a day. During high water level period Oct-Dec *Acadja*'s fishers hardly operate due to difficulties in harvesting. The same *acadja* is harvested once in about 2 months (based on interviews with the chief fisherman in Dzemeni).

Table 1.9. Catch per Unit of Effort (CPUE) by fishing gear and estimated annual fish catch from the Volta Lake at Dzemeni from March 2007 to June 2008. GN = gillnets, MNT = medium net trap, BT= basket traps AT* = acadja.

Gear	Mean no. of boats /day fishing in the area	Mean no. of fishing days per week (based on interviews)	CPUE daily (kg/boat/day) (based on the study of 11 fishers)	No. of fishing weeks (based on interviews)	Catch/week (tons) (calculated)	Catch/year (tons) (calculated)
GN	55	5	24.9	52	6.85	356.07
MNT	45	3	148.7	39	20.07	782.91
BT	50	3	156.9	35	23.54	823.73
TOTAL	150					1962.70

Discussion

Bio-physical parameters

The average values of temperature, dissolved oxygen and nutrients at all sites considered were comparable to what has been reported from similar areas in previous studies. Concentrations of nutrients were generally still low and may have implications for primary productivity of the Volta Lake. The low nutrient level of the Lake has been reported by previous researchers and was attributed the insoluble granite formations of the Volta basin (Antwi, 1990; Viner, 1969). Transparency was the only parameter that showed a dramatic change from a mean of about 134 cm since the early part of the Lake formation to below 50 cm during the current study. This is considered to be caused due to various anthropogenic activities around the Lake.

Fish Catch Assessment

Historical Perspectives:

The closure of the dam in 1964 led to the disappearance of some species especially from the genus of *Chrysichthys* which are sensitive to low oxygen levels. It also led to the disappearance of riverine species e.g., Mormyrids, *Brycinus*, *Hydrocynus* and schilbeids from the lacustrine area. The basic trend in the changes of the fish community was towards the development of a community of species with herbivorous food habits e.g., Tilapias, *Distichodus* and *Labeo*. Insectivorous species as e.g., *Alestes*, *Brycinus*, *Schilbeids*, *Chrysichthys* and some *Synodontis* species kept decreasing. Some 36 years later Tilapias dominated the catches until the late 1990s when *Chrysichthys* took over dominance all over the Lake.

Officially recorded total catch increased from 44,000 tons in 1976 to 60,000 tons in 1998. Over the same period, CPUE declined from 11 kg/boat/day in 1970 to 4kg/boat /day in 1998 presumably due to increased effort in terms of canoes rising from 9,113 in 1971 to 24,035 canoes in 1998 (MOFA, 2003). The increase in catch over the years was inversely related to changes in water level of the Lake.

Current situation:

Fish Species. The number of fish species encountered in the current study (32) is low compared to the 121 species listed for the Volta Lake (Dankwa *et al.*, 1999) and 60 commercially important fishes of the Volta Lake recorded by Denyo (1969). The low diversity encountered presently was attributable to the following two factors: i) the range of gears deployed in the previous studies were wider and were also different from those used in the current study, ii) studies were undertaken over longer periods and iii) may have presented different hydrological Lake conditions.

Catch Composition. Although 21 genera were represented in catches during the study, only 5 of them made up 96.9% and 84.1% of total numbers and weight of fish caught respectively. These were *Chrysichthys*, Tilapia, *Hydrocynus*, *Synodontis* and *Bagrus* (Fig.1.8). Previous studies also indicated dominance of a few fish groups in commercial catch on segments of the Volta Lake (Brammah, 1995; Abban, 1999). The extreme skew of catch towards a few species in catches of individual gears could be attributed to selectivity of the gears, which is an established phenomenon (Denyo, 1969). This being so it also reflects the actual species composition of the

Objectives CPWF Project Report

lake as fishers generally do optimize gears to available fish species and size classes. However, the predominant catch of *Hydrocynus* by one gillnet operator among the 11 fishers involved in the research was considered an innovation by that local fisher. Predominance of *Chrysichthys* in basket traps compared to heterogenous catch in net traps was attributable to *Chrysichthys* preferring 'darker' areas, while the preference of Tilapias for *acadja* could be attributed the attraction of these fish species that have an affinity for woody and vegetated areas in waters. (Hem *et al.*, 1994; Welcomme, 2000)

Relative catch per gear. Essentially, data obtained here suggested that locally evolved traps (basket and net traps) were most efficient in terms of the size (in weight) of the catch compared to gillnets. Even more important for fisheries management, was the indication that bigger mesh size gillnets were more effective in fishing in terms size of catch compared to smaller-meshed gillnets at least in certain periods of the year and for specific target species. It remains to be calculated how this difference works out in the economics of these fisheries.

Lake Water Level and Catch. Information available on the Volta Lake water levels suggests that water level had been decreasing for about 10 years and got to a lowest record in 2006. Since 2006, the situation started to improve. In relation to fish catch, data obtained during this study indicated higher species diversity in catch by all gears and higher CPUE at lower water levels within one year. Relationship between water level and fish catch usually requires temporal and spatial several considerations. However, the trends observed have been indicated by earlier authors including Leveque *et al.* (1998) and Paugy, *et al.* (1999) and van Zwieten *et al.* (2009).

1.1.3. Lake Nasser

Methods

Lake Nasser has a permanent storage of 31.6 cubic km, an active storage of 90.7 cubic km, and an emergency flood management storage of 41 cubic km. Lake Nasser has 84 side branches, known as *khors*. On the basis of ecological consideration, six *khors* were selected to cover different ecological conditions. They are: *Khor El Ramla* (R), *Khor Kalabsha* (K), *Khor Gurf Hussein* (GH), *Khor Korosko* (KR), *Khor Tushka East* (TE), and *Khor Tushka West* (TW) (Fig.1.13).

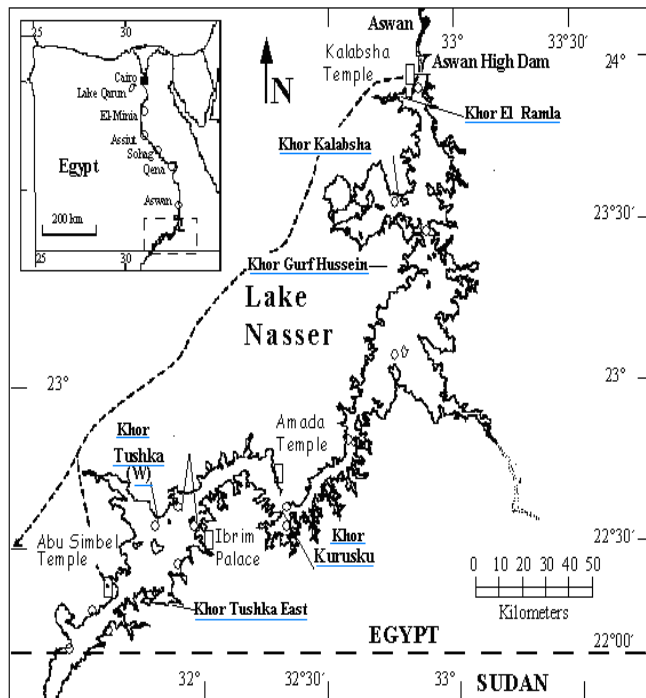


Fig.1.13. Map of Lake Nasser.

Lake wide surveys were done using the Research Vessel of Lake Nasser Development Authority in March 2006, February 2007, July 2007 and March 2008. The surveys covered also the enclosures used for fish stocking (see below). Chemical and physical parameters were analyzed according to the American Public Health Association (APHA, 1998). Oxygen concentrations were measured by Winkler method according to APHA (1995). Biological oxygen demand (BOD) was determined by using 5 days incubation method. The total viable bacterial counts (TVBCs) were determined using spreads-plate method (APHA, 1998). Chlorophyll-a (measured as indicator of phytoplankton biomass) was measured by Trichromatic method according to APHA (1995). Zooplankton samples were collected using standard closing plankton net, having 55 μ mesh size, 35cm mouth diameter and 80cm length. Samples were collected vertically from 5m deep up to the surface (photic layer) and from the aphotic layer (aphotic layer under the compensation level) at each station. Bottom fauna samples were collected by grab sampler.

Results

Transparency

The deepest water depth in the lake was 51.1 m at *Khor* El-Ramla. Water depths decreased from the entrance areas to shorelines of the *khors*. The lowest value of water transparency was 1m at *Khor* Tushka west, while the highest value of 5 m was measured at *Khor* El-Ramla. Water transparency direct proportional to water depths and decreased from the northern *khors* toward the southern ones.

Air and water temperature, pH

The lowest air temperature over Lake Nasser was 18.7 Celsius ($^{\circ}$ C) at *Khor* Tushka west in March, and the highest value was 31.1 $^{\circ}$ C at El-Ramal in July. The sub-surface water temperature (0.5 m) ranged between 19.4–23.9 $^{\circ}$ C at *Khor* Tushka west in March. At the same month, water temperature near bottom varied between 17.6 and 22.3 $^{\circ}$ C at *Khor* Korosko. The air and water temperature increased southward. The pH values ranged between 8.04 at *Khor* El-Ramla and 9.14 at *Khor* Tushka East in March. The pH values decreased southward. Total dissolved solids (TDS) values ranged between 135 mg l $^{-1}$ at *Khor* Korosko, and 185 mg l $^{-1}$ at *Khor* El-Ramla. TDS increased northward.

Oxygen, BOD and COD

Oxygen concentration varies seasonally, vertically and horizontally. It ranged between 3 and 12 mg l $^{-1}$ for the surface water, and from 0 to 8 mg l $^{-1}$ for bottom waters in July. In summer, thermal stratification is noticeable, with oxygen reaching 0 mg l $^{-1}$ at depths below 15m. The obtained results of biological oxygen demand (BOD) showed a regular distribution trend along the selected *khors*. Generally, the values decrease in the main channel and gradually increase at the two bank sides. The minimum value (0.8 mg/l) was recorded at the entrance of *Khor* Tushka East while the maximum value of 4.4 mg l $^{-1}$ was recorded at the southern side of the same *khors* in March. The results of chemical oxygen demand (COD) showed a similar distribution trend as BOD values along the selected *khors*. Values decrease in the main channel (mean average 6.4 mg l $^{-1}$), and gradually increase at the two sides with mean average of 7.4 mg l $^{-1}$ during March. The minimum value (0.98 mg l $^{-1}$) was recorded at the middle layer of first sector in *Khor* Gurf Hussein, while the maximum value of 15 mg l $^{-1}$ was recorded at the surface layer in *Khor* Tushka East in winter.

Carbon

In most sites carbonate appear to be completely depleted in the main channel of the *khors*, while it was observed in most of the two bank's sites in the selected *khors*. The highest carbonate value (18.0 mg l $^{-1}$) was recorded in the southern side of the middle sector in *Khor* Gurf Hussein in March. Bicarbonate values exhibit a regular homogenous distribution in the main channel at the selected *khors* with its highest values (132 mg l $^{-1}$) in the surface layer of main channel of second sector in *Khor* Gurf Hussein in July. Its values however decreased presumably as a result of remarkable values of carbonates. The lowest value of bicarbonate (84 mg l $^{-1}$) was recorded in the southern side of the middle sector in *Khor* Gurf Hussein in March.

Objectives CPWF Project Report

Sulphate, calcium and magnesium

Sulphate results showed gradual increase southward along the selected *khors*, especially in the *Khor Tushka West*. The highest value (19.4 mg l^{-1}) was recorded in the northern side of the first sector at *Khor Tushka East*, while the minimum one (11.96 mg l^{-1}) was recorded at the surface layer of the main channel of first sector in *Khor El-Ramala* in March. Calcium results showed regular distribution pattern along the studied *khors*, with higher figures along the two banks as compared to the main channel in the same *khor*. The highest value (28.86 mg l^{-1}) was recorded in the northern side of the second sector at *Khor El-Ramala*, while the minimum one (12.83 mg l^{-1}) was recorded at middle layer of the entrance sector of *Khor Korosko* in March. The highest magnesium value (20.38 mg/l) was recorded in the northern side of the first sector at *Khor Tushka West*, while the minimum one (9.7 mg l^{-1}) was recorded at southern side of second sector in *Khor Korosko* in March.

Nitrogen

Nitrite results showed an increase in southern *khors*. The highest value ($44.1 \text{ } \mu\text{g l}^{-1}$) was recorded near the bottom water layer in the main channel of the first sector at *Khor Tushka West*, while the minimum one ($2.4 \text{ } \mu\text{g l}^{-1}$) was recorded at middle layer of the entrance sector of *Khor El-Ramala* in March. Nitrate concentrations showed a similar trend as nitrite. The results of ammonia in the main *khors* in Lake Nasser exhibit homogenous distribution pattern, whereas their values fluctuated in a narrow range. The highest value ($127.4 \text{ } \mu\text{g l}^{-1}$) was recorded in the middle water layer in the main channel of the first sector at *Khor Tushka East* in July, while the minimum one ($12.4 \text{ } \mu\text{g l}^{-1}$) was recorded at northern side of second sector at *Khor Gurf Hussein* in March.

Chlorophyll a

Overall the concentrations of chlorophyll *a* at Lake Nasser ranged between $1.59 \text{ } \mu\text{g l}^{-1}$ to $6.1 \text{ } \mu\text{g l}^{-1}$ during the year. Regarding vertical distribution of chlorophyll *a*, the result showed that the highest value of chlorophyll *a* was found at depth of 5 meter from the surface, due to absence of light penetration.

Algal composition and epiphytes

Chlorophytes were the most occurred group, 75 species constituted this group with relative occurrence of 41.9%. Diatoms ranked the second position with relative occurrence of 30.7% (55 diatom species were identified) while Cyanophytes ranked the third position with relative occurrence of 26.3% (47 species were recorded). The highest diatom abundance of $6148.5 \times 10^3 \text{ cells cm}^{-2}$ was obtained at *Khor Korosko* in July, while the minimum one of $120.3 \times 10^3 \text{ cells cm}^{-2}$ was found at *Khor Kalabsha* in March. Epiphytic biomass per lake littoral surface area is considered very high compared with the corresponding phytoplankton chlorophyll *a* values. The small taxa like *Cymbella microcephala*, *Fragilaria constreuns*, *Achnanthes minutissima* and *A. lanceolata* dominated in the *khors* present in the middle of the lake, considerable large cells belonging to *Epithemiaceae* and *Cymbella obscura* dominated in the *khors* at the middle of the lake.

Zooplankton

The maximum number of zooplankton organisms was recorded in *khor Tushka East* ($98 \times 10^3 \text{ org. m}^{-3}$) in March, while the lowest number was recorded in *khor Korosko* ($67 \times 10^3 \text{ org. m}^{-3}$) in March as shown in Fig.1.14. Main zooplankton groups include rotifera, cladocera, and copepods.

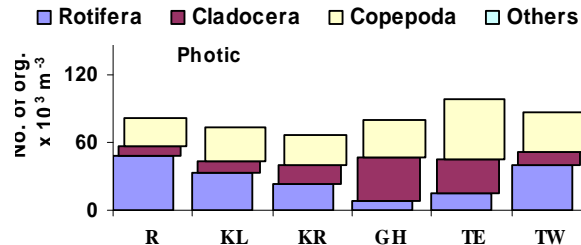


Fig.1.14. Zooplankton abundance at the six studied *khors*

Benthic fauna

The biomass values of bottom fauna in the western side of the lake in March were higher than those recorded in the eastern one. This increase in the biomass was associated with the increase of Mollusca at these stations. In March 2006, the bottom fauna showed a high population density in *Khor Gurf Hussein*, where 24,150 individuals m⁻² weighting 227 g m⁻² were recorded. The lowest population density was recorded at *Khor Tushka East* in Feb 2007 with value of 12,700 individuals m⁻², weighting 113 g.m⁻². *Khor Kalabsha*, *Khor Korosoko* and *Khor Tushka West* shown recorded values of 21,400, 20,250 and 19,100 individuals m⁻², weighting respectively 291, 333 and 258 g m⁻². Mollusks, aquatic insects, annelids, and crustaceans are the main groups of bottom fauna.

Fisheries production

Fish landing from Lake Nasser from 1965 to 2005 is presented in Fig.1.15. The total fish landing increased with increase in water level in the lake from 1965 to 1981 to reach 35,000 ton at 1981, then decreased again from 1981 to 1986 as a result of drought and subsequent decrease in the lake water level. Starting from 1986 fish landings showed abrupt changes that were not related to water level but due to price fixation and consequently smuggling of fish (see section 2 below).

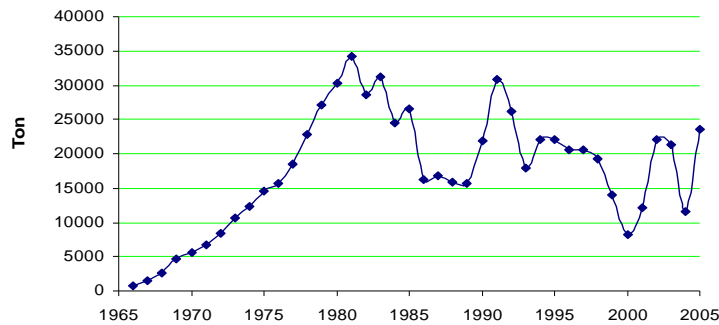


Fig.1.15. Fish landing from Lake Nasser from 1965 to 2005 (LNDA Statistics).

Species composition of fish caught during the project in experimental fishing carried out in Mar-06 (sample No=336), Feb-07 (sample No=323), July-07 (sample No=456), and Mar08 (sample No=414) in the North part (sample No=606) and South Part (sample No= 923) with Trammel net (inner 3cm and outer 7cm; Gill nets 3.5 and 6 cm). Results are shown in Table 1.10. Average catch per unit effort (CPUE) computed as the catch in kg of fish by 50m length of the net in a unit of time (one night for gill net or one shot of trammel net) (Table 1.11).

Table 1.10. Species composition in weight (Wt%) and number (No%) for different gear types in Lake Nasser during the study period based on 1529 samples caught with mesh bar sizes (Trammel net, inner 3cm and outer 7cm; Gill nets 3.5 and 6 cm).

Region	North Part		South part	
Species	Wt %	No %	Wt %	No %
Trammel net				
<i>O. niloticus</i>	18.54	10.61	78.07	59.77
<i>S. galilaeus</i>	61.99	77.49	8.07	16.8
<i>T. zilli</i>	5.38	6.71	4.27	8.2
<i>L. nilotica</i>	5.4	2.81	1.52	3.91
Total %	91.32	97.62	91.93	88.67
Gill net				
<i>H. forskalii</i>	19.25	13.12	34.60	23.12
<i>A. dentex</i>	30.46	35.11	18.80	29.48
<i>O. niloticus</i>	23.07	8.33	4.00	1.73
<i>L. nilotica</i>	7.97	8.33	12.69	12.14
<i>S. galilaeus</i>	10.13	22.34	0.71	1.73
<i>T. zilli</i>	4.45	7.09	1.71	4.62
Total %	95.33	94.33	72.52	72.83

Objectives CPWF Project Report

Table 1.11. CPUE (kg/50m-net/ night or shot) for different gear types and parts of Lake Nasser during the study period (mesh bar sizes trammel net, inner 3cm and outer 7cm; gill nets 3.5 and 6 cm, total sample No=1529 with trammel net sample No=1019 and gill net sample No=510).

Area	Net Type	CPUE
North	Gill net	1.47
	Trammel net (Duk)	7.08
South	Gill net	2.67
	Trammel net (Duk)	3.99

Six fish species dominated the catch of the different regions of the Lake; namely *Oreochromis niloticus*, *Sarotherodon galilaeus*, *Alestes dentex*, *Hydrocynus forskalii*, *Lates niloticus* and *Tilapia zillii*. A few other species were recorded: *Bagrus bayad*, *Bagrus docmac*, *Tetraodon fahaka*, *Mormyrus kannume* (I: Bouiza), *Chrysichthys auratus*, *Barbus bynni*, *Heterobranchus bidorsalis*, *Synodontis schall*, *Labeo niloticus* and *Clarias lazera*. Size ranges of fish caught are described in Table (1.12).

Table 1.12. Size indicators in standard length (SL) and total weight (Wt) for different gear types and parts of Lake Nasser during the study period (mesh bar sizes trammel net, inner 3cm and outer 7cm; gill nets 3.5 and 6 cm, total sample No=1529).

Species	Northern Part				Southern part			
	Mean SL (cm)	Range of SL (cm)	Mean Wt (gm)	Wt Range (gm)	Mean SL (cm)	Range of SL (cm)	Mean Wt (gm)	Wt Range (gm)
Trammel net								
<i>O. niloticus</i>	19.47	12-33	370.2	70-1660	23.83	14-39	616.61	160-2000
<i>S. galilaeus</i>	15.44	7-19	169.41	250-410	17.62	15-21	226.74	153-330
<i>T. zilli</i>	15.76	10-22	169.77	45-410	18.05	14-41	245.86	92-1160
<i>L. niloticus</i>	26.53	20-35	406.75	147-900	20.56	15-28	183.2	70-380
Gill net								
<i>H. forskalii</i>	32.28	21-65	440.28	110-3325	33.08	23-45	452.3	145-1300
<i>A. dentex</i>	28.27	21-34	260.4	130-440	24.81	20-37	192.78	110-555
<i>O. niloticus</i>	27.46	14-56	830.96	105-1950	21.67	18-26	696.33	105-1950
<i>L. niloticus</i>	22.54	14-38	286.94	65-2200	24.32	19-37	315.95	130-970
<i>S. galilaeus</i>	14.63	11-22	136.10	70-560	14.33	11-16	124.00	72-150
<i>T. zilli</i>	16.24	13-21	188.50	90-520	13.26	10-17	111.88	50-185

Discussion

The main factors that have so far been affecting the recorded fish production in Lake Nasser are water level and the institutional context (e.g. the existence of a fixed price system for fresh fish – see below section 2). Fluctuations in lake water volume alters the ecology of a large portion of the Lake, decreasing sharply the spawning and nursery areas and, consequently, fish production when water level decreases –as it was the case for instance during the drought years from 1981 to 1986 during which fish landing decreased significantly.

Referring to biophysical data, and comparing primary productivity, it was noticed that there was limited change over time in Chlorophyll a concentrations. It is possible to calculate the maximum yield of fish production from the lake from Chl a concentrations. The average primary net production of phytoplankton is estimated to be 4 kg (d.w.) m⁻² year⁻¹, and considering that the total surface area of lake Nasser was estimated to be 2562 km² (2.56 x 10⁹ m²) at 160 m water level, and 5237 km² (5.23 x 10⁹ m²) at 180 m water level, the total catch was estimated to be 22.7 x 10³ ton/year at 160m water level and 46.2 x 10³ ton/year at 180m water level. The average is about 34,500 ton which is very close to the maximum total catch that was recorded in 1981. It seems that the lake is very stable ecologically.

Enclosures and restocking of enclosures

Tilapia species, *Oreochromis niloticus* and *Sarotherodon galilaeus* are identified as plankton feeder. During their early life stages up to fingerlings they feed mainly on zooplankton. Adult tilapiins are herbivorous, mainly feeding on epiphytes, macrophytes and attached algae which are also dominant with high densities in *khors*. The ecological conditions in the lake, especially in *khors*, are in favor of the reproduction, growth and feeding of tilapiine species. The spawning season of these species is synchronized with the maximum zooplankton density (early spring). Economically, increased abundance of both tilapiin species would be considered suitable. A fishery based on these herbivorous fish will therefore be more productive than one based mainly on species higher in the web chain such as *Synodontis schall*, *Tetradon fahaka*, or *Clarias Lazera*.

Productivity levels and tilapiine species composition, however, differ. The southern region is richer in zooplankton than the northern region which may be attributed to the continuous flow of nutrients resulting in high productivity of phytoplankton essential for zooplankton. Generally, higher fish yield were recorded in the southern region of the lake, particularly close to Allaqi, Korosko and Toshka, where higher mean annual values of chlorophyll-a and zooplankton were recorded. The current estimates of CPUE do not contradict these observations, but differ between gears. The mean value of CPUE of gillnets used in the south was 1.82 times higher than in the north while CPUE of trammel nets in the north was 1.77 higher than in the south. Most of the fish caught in the north (62%) was of *S. galilaeus* with an average length of 15.4 cm (169 g), whereas the catch in the south was mainly *O. niloticus* (78%) of an average length of 23.8 cm (616 g).

Increasing productivity through species introductions

Although the open water areas are rich in phyto- and zooplankton, acoustic surveys were not able to detect fish populations in the main channel. Anoxic conditions and thermal stratification was noticed at depth >20m, with zero oxygen concentration in summer season. Special attention should therefore be given to the upper layer of open water areas of the lake and the potential for pelagic fish species to occupy this niche. Silver carp was tried as plankton feeder in floating cages set in the offshore area but was not pursued further due to many reasons (consumer's strong preference for tilapia, possibility of escape from the cages with potential impact on the tilapiine population as the two species would compete for the same food). Other species that could be considered are the true pelagic species as *Limnothrissa miodon* (kapenta) that was successfully introduced in a number of reservoirs in Southern Africa. However, as the lake is the main source of potable water for the very large majority of Egyptians, any introduction of new species should be treated with extreme caution due to its potential to change the lakes conditions.

1.1.4. General consideration on reservoir productivity

Generalisation about capture fish production per water surface area is difficult both due to the lack, or unreliability, of catch data and the paucity of data on water surface area in many countries. Productive reservoir fisheries have developed in small reservoirs in Africa with yields of up to 329 kg ha⁻¹year⁻¹, in Latin America and the Caribbean with yields up to 125 kg ha⁻¹year⁻¹ and in Asia with yields up to 650 kg ha⁻¹year⁻¹ (SOFIA 2002). By comparison, the estimated productivity of all Indian reservoirs (ranging between 11-46 kg ha⁻¹) as well as the one from Lake Nasser of 36.4 kg ha⁻¹ is extremely low. In contrast the productivity of Lake Volta, assuming a catch of 250,000 tonnes and an area of 8500 km, seems high with 294 kg ha⁻¹ and even with the official (underestimated) landing statistics it would still be producing between 51-88 kg ha⁻¹. The low productivity in Nasser and the Indo-Gangetic basins thus may be a function of underreporting of catches, as with many other inland fisheries. Even so, in the case of Lake Nasser, if one assumes that the reported landings represent only 50% of the total landings as reported (see section 2.3.2 below), the production per ha is still only 73 kg ha⁻¹, comparable to low productive reservoirs in China (79kg ha⁻¹) Thailand (74 kg ha⁻¹) and Indonesia (64 kg ha⁻¹). The productivity of Lake Nasser therefore may be indicative of the underutilisation of the available resources.

It is difficult however to directly compare these data on yields per hectare, as yield generally is not proportionally related to the lake size. A direct comparison is possible, though, when calculating

Objectives CPWF Project Report

annual yields for a hypothetical 1000 ha lake based on log-log regressions of yield and lake area (Fig.1.16) (Kolding and van Zwieten, 2006; van Densen et al. 1999).

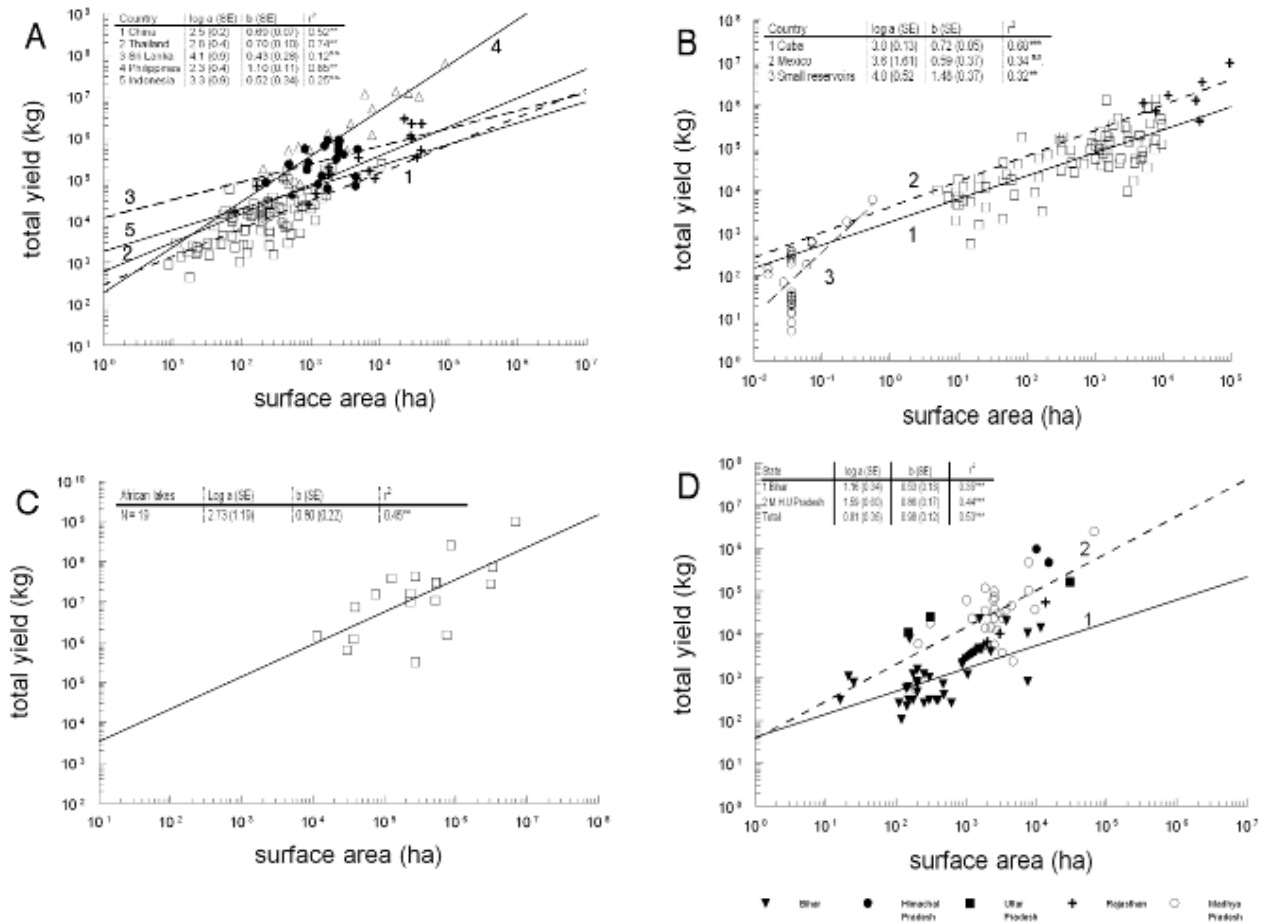


Fig.1.16 A. Plot of total yield (kg) on surface area (ha) for 1. (open squares) 83 reservoirs in China; 2. (crosses) 20 reservoirs in Thailand; 3. (dots) 19 reservoirs in Sri Lanka; 4. (triangles) 17 Philippine lakes and 5. (open circles) 9 reservoirs in Indonesia. B: Plot of total yield on surface area for 1. (open squares) 86 reservoirs in Cuba; 2. (crosses) 7 reservoirs in Mexico; 3. (open circles) 31 small reservoirs in Brazil, 1 in Peru, 1 in Costa Rica, 4 in others. C. Plot of total catch on surface area for 19 African lakes and reservoirs. D. Plot of total yield on surface area for reservoirs in Madhya Pradesh (27), Rajasthan (20), Uttar Pradesh (4), Himachal Pradesh (2) and Bihar (33).

This analysis, based on a selection of water bodies for which information was available provides estimates of annual average yields in Asian waters of 365 kg ha⁻¹ for Philippine lakes, 239 kg ha⁻¹ for Sri Lankan reservoirs, 79 kg ha⁻¹ for Chinese reservoirs, 74 kg ha⁻¹ for Thai reservoirs and 65 kg ha⁻¹ for Indonesian reservoirs (Fig.1.16 A). Similar regressions for South American reservoirs suggest annual yields for a 1000 ha reservoir of 144 kg ha⁻¹ for Cuba and of 234 kg ha⁻¹ for Mexico (Fig.1.16 B). Using the same approach, a hypothetical African lake of 1000 ha would produce 168 kg ha⁻¹ (Fig.1.16 C). In comparison, medium sized Sri-Lankan reservoirs are highly productive with catches reaching sometimes well above 200 kg.ha⁻¹.yr⁻¹. These catches are dominated by the introduced tilapia which is produced without supplementary stocking.

Following a similar analysis a hypothetical 1000 ha Indian reservoir yields one factor less with an average of 20 kg.ha⁻¹ (Fig.1.16 D). By overall comparison this is anomalously low and seems to be far below the potential yield these reservoirs could yield. It is not clear from the general literature what causes this low productivity in the Indo-Gangetic basin reservoirs. This is generally

thought to be due to the lack of understanding of reservoir ecology, trophic dynamics, inadequate stocking, wrong selection of species for stocking, low size of stocking materials and “irrational” exploitation” (CIFRI 2006). To these may be added the impacts of hydrological regimes for electricity generation or irrigation that may not fit species habitat and spawning requirements as well as the management regimes regulating the fishing effort and fishing patterns. What is clear, however, is that a thorough study of the possible causes is warranted. The causes may not be wholly ecological but related to overall effort levels as well as management regime, suggesting that the theoretical potential for improvement is very high.

1.2. Fisheries enhancement tools: implementation

1.2.1. General introduction of the section

We presented above an overview of the bio-physical and ecological dynamics of the reservoirs under consideration in the three basins. In the section below we now turn to the ‘core’ objective of this first part of the project, namely, identifying, developing, and testing fisheries enhancement tools and strategies, with the hope that those will lead to increased fish productivity and better community livelihood prospects. Three main interventions directly related to fisheries productivity were implemented in the three basins:

- small-scale cage culture in Lake Volta,
- *khor* enclosure in Lake Nasser,
- cage and pens in India.

The first part of the section below will present in detail the rationale, methods, results of those three different efforts to increase productivity, followed by a general discussion.

1.2.2. Cage Culture in Lake Volta

Justification and choice of the fisheries enhancement techniques

For the Volta Basin, the site where the enhancement model was to be tested had been determined in advance during the proposal design. This was the Lake Volta. In this context, the two potential approaches that were then envisaged for enhanced fish productivity in the Volta Lake were:

- management of stocks through control of fishing gear and
- culture based fisheries approaches.

Consultations with primary stakeholders³ indicated that culture based fisheries options especially artisanal caged fish culture and penned fish culture systems were preferred.

Cage aquaculture is practiced profitably in many parts of the world, generating jobs and making substantial contributions to fish supply (Hambrey 2006). From interviews with some of the major producers, current output of Nile tilapia cage aquaculture in sub-Saharan Africa can be estimated at about 4500 tonnes per annum, mostly from relatively large-scale, commercial projects in Ghana, Malawi and Zimbabwe.

In Ghana, the government is actively promoting aquaculture development as a way to reduce the country’s current fish supply-demand gap. As part of this policy, one percent of the total surface area (8,700 km²) of the lake has been allocated to the development of cage aquaculture (Personal

³ Consensus building workshop I (22nd March 2006) –see Table 3.1 below. During this workshop, the project’s broad concept, objectives, main strategies and vision were introduced and discussed with an identified Fisheries Dependent cluster of Communities (FDC) including opinion leaders representatives of satellite communities, fisheries associations, District Assembly, District Ministry of Fisheries, District Ministry of Health and District Chief Executive after a series of consultations with Chief and elders. Issues discussed included the type of fish catch data available to local fishers, the relevance of Community-based fisheries resources management, efforts at reducing fish processing losses and the concept of culture-based fisheries for increasing fish production.

Objectives CPWF Project Report

Communication, Hon. Gladys Asmah, Ghana Minister of Fisheries, Accra, 30 March 2007) with the hope that this initiative will actively encourage investors.

If the yields reported for cage aquaculture elsewhere in Africa, i.e. between 50 and 150 kg/m³/9 months⁴, can be replicated in Ghana, production from less than 100 ha of fish cages could just about match the current capture fishery output of about 90,000 tonnes (Asante 2006). Conjointly, positive cash-flows have also been reported for medium-scale production systems with outputs of approximately 20 tonnes per month. The stocking, feeding and cage construction technology piloted by these farms was thought to be suitable to smaller-scale investors.

The intention was therefore to design small cage technology model for local communities, to assess the local adaptability of this system by running an experimental trial, with the explicit objective to evaluate the production capacity and economic viability of the system, assess the technical manageability of the approach, identify potential key production constraints and technical difficulties, and determine the minimum scale for economic sustainability⁵.

Methods

The lee of a small-uninhabited island off of the fishing and trading community of Dzemeni, South Dayi District, on the South West bank of the Volta Lake in Stratum II was chosen to run the trial. From October 2005 through December 2007, two six-month cycles of small-scale pilot cage aquaculture were carried out. In the first trial, four cages each of 6 x 4 x 2 m deep (48 m³) were used. The cages were constructed entirely of locally available materials (Photos 1.1) at an individual cost of approximately \$1000 (Table 1.13). For the second trial, an additional two cages were installed for a total of six.



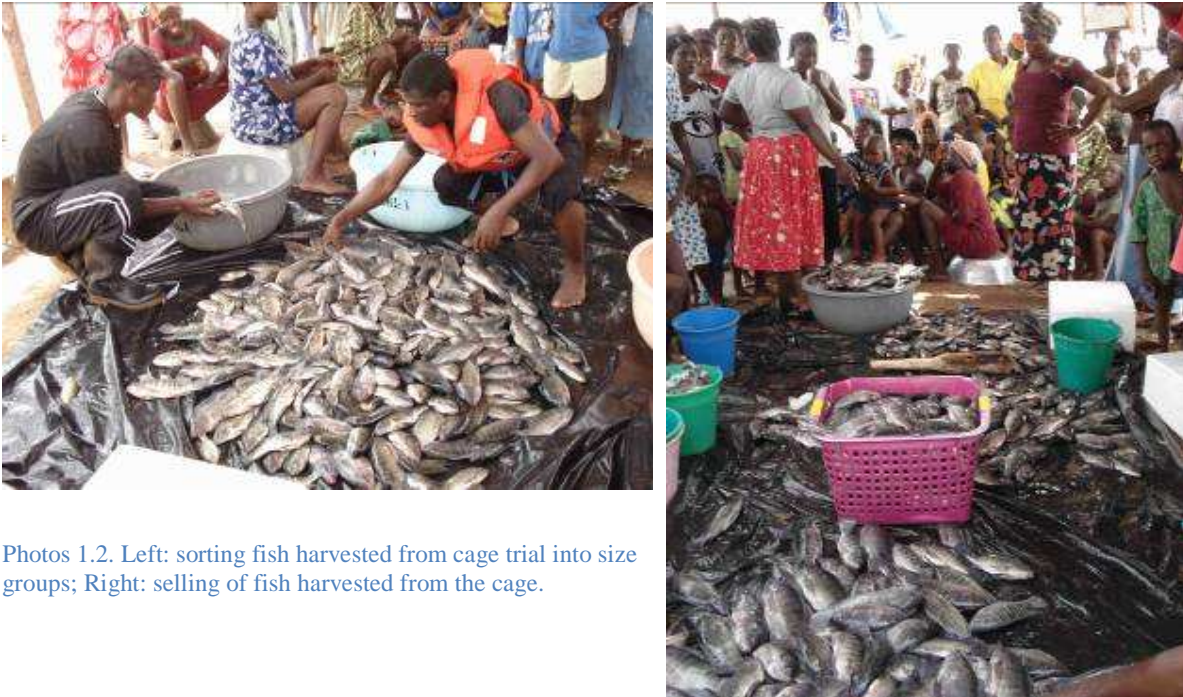
Photos 1.1. Cages used for the trial (Lake Volta)

Mixed-sex fingerlings derived from a selected line of *Oreochromis niloticus* produced at the Ghanaian Aquaculture Research and Development Centre (ARDEC) in Akosombo, and reported by WRI to grow some 10-15% faster than the local wild stock, were stocked at rates ranging from 3000 up to 9000 fish per cage (63 to 188 fish m⁻³). Heavy mortalities incurred, however, due to poor transport and handling conditions, resulting in effective stocking rates of between 20 and 100 fish m⁻³ with fingerlings of between 13 and 32 g (Table 1.14 a).

⁴ Personal Communication to R. Brummett by Patrick Blow, Lake Harvest Aquaculture, 31 October 2006 and Karen Veverica, Jinja, Uganda, 21 November 2007.

⁵ For detail see Ofori J.K., Abban E.K., Karikari A.Y. and Brummett R.E. (2009) Production of small scale tilapia cage culture in tropical reservoirs: a study in the Volta Lake, Ghana Journal of Applied Aquaculture (in press).

Fish in cages were fed locally available (GAFCO Inc.) floating extruded pelleted aquafeed containing approximately 30% crude protein. After 133 to 153 days, the cages were harvested, fish graded according to size class (>300 g, 200-300 g, <200 g), counted, weighed and sold to local fish traders to estimate their commercial value (Photos 1.2).



Photos 1.2. Left: sorting fish harvested from cage trial into size groups; Right: selling of fish harvested from the cage.

Table 1.13. Construction costs for a 48m³ small-scale aquaculture cage manufactured from locally available materials in Dzemeni, Ghana (1 USD = 0.92 Ghana ¢).

Item	Description	Quantity	Unit cost	Total (Ghana ¢)	Total (US\$)
Galvanized pipe	1.5" - 2"	12	18	216	235
Floats	Plastic barrel (250 l)	8	30	240	261
Nets	15 mm stretched mesh	40 m	4.375	175	190
Shackles		16	3	48	52
Hapa nets	40m	0.5	100	50	54
Rope	10mm	2 coils	20	20	22
	6mm	1 coil	5	5	
Anchors	0.3m3	6	5	30	5
Welding			50	50	33
Cage cover net	6m x 5m	1	12	12	54
Labour		1	30	30	13
Total				876	33

During the first trial, water quality was monitored every two months. In an attempt to estimate the impacts of cage aquaculture on water quality, sampling stations were located 10 m upstream and 30 m downstream of the cage installation. Temperature and pH were measured in the field with a temperature probe and a HACH EC 20 portable pH meter, respectively. Samples for analysis in the laboratory were collected from near the top of the water column, at mid-cage depth (1 m) and near the bottom in 300 ml plain glass bottles. Electrical conductivity was measured with a Cyberscan 510 meter and turbidity was measured with a HACH 2100 P Turbidimeter. All other analyses followed standard methods (APHA 1998): Diazotization for NO₂-N; Hydrazine Reduction

Objectives CPWF Project Report

for NO₃-N; Direct Nesslerization for Total Ammonia Nitrogen; Stannous Chloride for Phosphate; and the Azide modification of Winkler for Dissolved Oxygen.

Table 1.14 a. Fish stocking, growth and harvest data for the first of two pilot cage trials

	Cage 1	Cage 2	Cage 3	Cage 4
Date Stocked 2006	27/10	08/12	31/10	31/10
No. Stocked	4000	6000	7000	2780
Avg. wt at stocking (g)	13.4 ± 10.33	25.0 ± 4.14	12.9 ± 7.97	31.7 ± 15.02
Avg. wt at harvest (g)	207.5 ± 59.98	277.5 ± 42.36	219.7 ± 88.27	307.5 ± 134.19
Grow-out (days)	153	147	133	152
Biomass GR (kg/day)	2.69	9.05	7.1	4.14
No. Fish at harvest	1946	4639	1079	1647
Survival (%)	48.70	77.3	15.4	59.2
SGR*	1.79	1.64	2.13	1.49
FCR	2.64	2.50	3.51	2.97
Gross yield (kg/cage)	324.7	1175.7	247.1	402.5
Net yield (kg/cage)	270.9	1025.7	221.3	314.3

Table 1.14 b. Fish stocking, growth and harvest data for the second of two pilot cage trials

	Cage 5	Cage 6	Cage 7	Cage 8	Cage 9	Cage 10
Date Stocked 2007	31/1	6/7	7/3	31/08	18/07	7/7
No. Stocked	7500	8200	7500	9000	6000	6000
Avg. wt at stocking (g)	22.92 ± 9.75	22.88 ± 8.75	12.45 ± 4.92	12.45 ± 4.90	20.08 ± 9.32	20.13 ± 9.34
Avg. wt at harvest (g)	369.70 ± 155.5	452.2 ± 230.3				308.1 ± 141.2
Grow-out (days)	169	147				130
No fish at harvest	1480	523	Net caught on bottom and torn open; last sample 10/01/08 avg wt 318g	Net slashed by fishers; last sample 25/10/07 avg wt 86.2g	Poisoned by fishers; last sample 23/12/07	1542
Survival (%)	20	6.4				25.7
SGR*	1.65	2.03				2.10
FCR	2.64	2.5				8.05
Gross yield (kg/cage)	324.7	232				503.4
Net yield (kg/cage)	270.94	44.38				389.68

*Specific Growth Rate (%/day) = \ln Average Final Weight – Average Initial Weight/growth period (days)

Results

Production and growth data from the trials are shown in Table 1.14 a-b and Fig. 1.17 a-b. Two cages were sabotaged by locals and another was damaged as it became fouled with a submerged tree when the water level was low and then ripped open, releasing the fish, as the water level rose again. For those cages that survived the entire trial, gross yield ranged from 232 to 1176 kg cage⁻¹ 6 months⁻¹ (5-25 kg m⁻³) averaging 456 ± 329.5 kg cage⁻¹ (9.5 kg m⁻³). Overall, survival was low in all cages, averaging 29 ± 28.4%. Only about 30% of the mortalities floated up and were counted, at least another 40% sank or went unnoticed.

Only the cage No.2 from which more than one tonne of fish (>96 fish weighing 24.5 kg m⁻³) was harvested made a significant profit (Table 1.15). Food conversion ratios (FCR) were estimated to range between 2.5 and 8.1 with an average of 3.54 (Table 1.14 a and b). Feed was the major component of cost, averaging over 50% of the total (Table 1.16). Fingerling purchase was another major cost, accounting for an average of 27% of the total.

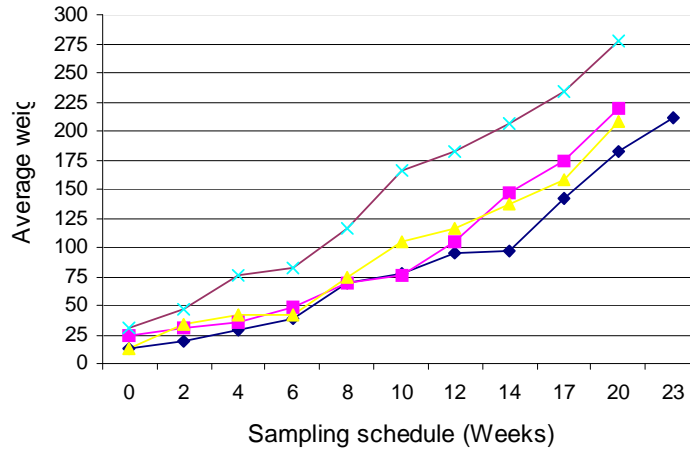


Fig.1.17 a. Growth pattern of *Oreochromis niloticus* (trial 1). Fish stocked at approximately 40 fish/m³ were fed a commercial diet over a culture period of six months.

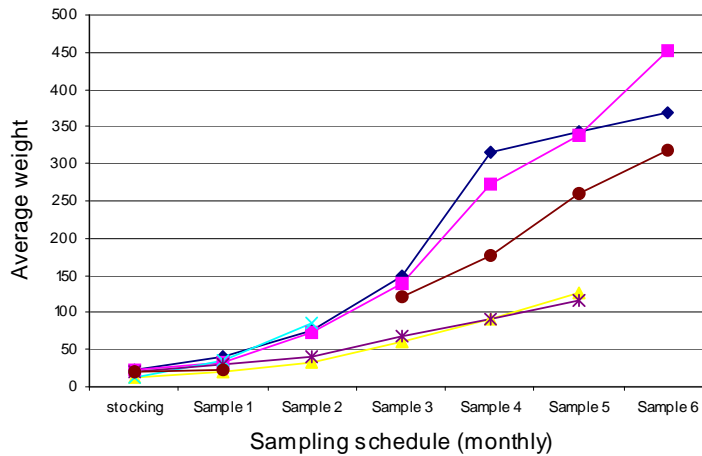


Fig 1.17 b. Growth pattern of *Oreochromis niloticus* (Trial 2). Fish stocked at approximately 40 fish/m³ were fed a commercial diet over a culture period of six months. Three cages were damaged or sabotaged and harvested early.

The WRI Akosombo Improved Strain exhibited an average specific growth rate in cages of 1.83% body weight per day (Table 1.14), but showed significant variation in final weight at harvest, ranging between 60 and 500 g. Overall, small fish (<200 g) averaged 17.5 ± 19.73%, medium fish (200-300 g) averaged 27.1 ± 9.9% and large fish (300-500 g) averaged 54.4 ± 24.1% of the harvest by weight (Table 1.17). The average price received from fish mongers on the shore within an hour after harvest was ₵3.14 per kg live weight.

Table 1.15. Economic analysis (1 US\$ = 1.12 Ghana ₵).

	Cage 1	Cage 2	Cage 3	Cage 4	Cage 5	Cage 6	Cage 10
Fixed cost*	109.5	109.5	109.5	109.5	109.5	109.5	109.5
Variable costs	1,760.76	2,700.00	2,458.70	1,468.06	1,598.0	1,867.0	1,687.0
Total cost	1,870.26	2,809.50	2,568.20	1,577.56	1,707.5	1,978.5	1,756.5
Revenue	812.82	3,527.04	741.3	1,207.50	1,136.4	812.00	1,760.1
Net Income	-1,057.44	717.54	-1,826.90	-370.06	-574.1	-895.50	4.50

* For the cage, amortized over 4 years.

Objectives CPWF Project Report

Although water level varied by up to 1.2 m and flow rate was at times nearly undetectable, water quality in the vicinity of the cages was generally stable and remained within the limits for good tilapia growth throughout the trials (Table 1.18) (Boyd 1990). No fish deaths attributable to poor water quality were recorded. In addition, there was no obvious impact of aquaculture on water quality in the immediate vicinity of the cages (Fig.1.18).

Table 1.16. Cost of production, revenues and return on investment (ROI) (1 US\$ = 0.92 Ghana ¢).

	Quantity	Unit Value (GH¢)	Amount (GH¢)
Cost Elements			
Cage (amortized over 4 yrs)	1/2	219.00	109.5
Fingerlings	6000	0.12	720.00
Feed	3000	0.49	1470.00
Labour (person-month)	6	60.00	360.00
Marketing			50.00
Transportation			100.00
Total cost			2809.50
Revenues			
Total harvest (kg)	1176	3.00	3528
Net Income			718.54
ROI			25.6%

Table 1.17. Proportion of large (>300g), medium (250-300g) and small (<250 g) fish obtained over the six month trial

Size category	Percentage composition per cage per location						
	Cage 1	Cage 2	Cage 3	Cage 4	Cage 5	Cage 6	Cage 10
Small	49	11	42	7	6	2	13
Medium	32	32	32	42	19	17	16
Large	19	57	26	51	75	81	71

Table 1.18. Mean \pm standard deviation of water quality parameters measured bi-monthly (n=10) at mid-cage depth (1 m)

Temp. °C	pH	Turbidity (NTU)	Transp. (cm)	Electrical Conduct. ($\mu\text{S cm}^{-1}$)	NO ₂ -N (mgL ⁻¹)	NO ₃ -N (mgL ⁻¹)	NH ₄ -N (mgL ⁻¹)	PO ₄ -P (mgL ⁻¹)	DO (mgL ⁻¹)
30.5	7.72	3.28	140	59.29	0.008	0.41	0.18	0.17	7.90
± 1.30	± 0.61	± 0.57	± 18.8	± 1.627	± 0.007	± 0.42	± 0.14	± 0.11	± 1.27

Discussion

Improper handling and transport of tilapia fingerlings destined to be stocked in the cages was the major cause of low yields and profits. Typical survival rate in small-scale tilapia cage culture is in the range of 70-80% (Mikolosek et al. 1997, De La Cruz-Del Mundo 1997) although survival as low as 60% has been associated with stocking densities in excess of 70 fish m⁻³ (Yi et al. 1996). In a similar artisanal cage system tested in Côte d'Ivoire by Gorissen (1992), stocking mortality in 30 m³ cages stocked with 30 g fingerlings at 100 m⁻³ was only 5.2%, implying that the problems encountered at Dzemeni can be remedied with proper fish handling techniques, even under rustic conditions. Simple linear regression of the number of marketable fish at harvest against net profit ($y = 1.2x + 2521$; $R^2 = 0.54$) suggests that a farmer using a system similar to that tested at Dzemeni would need to produce over 50 fish with an average weight of over 300g per cubic meter of cage volume to break-even.

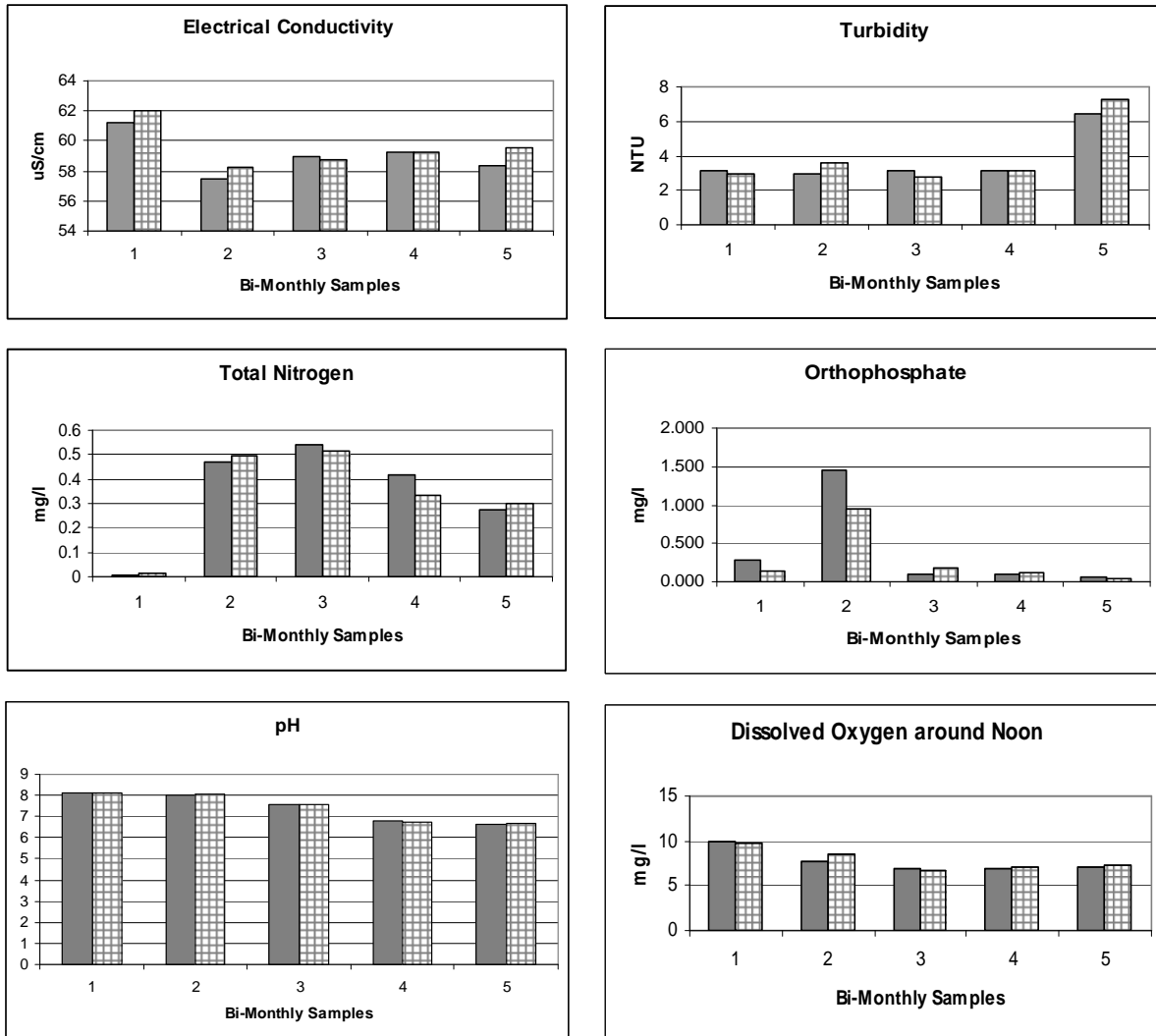


Fig.1.18. Trends in key water quality parameters sampled every 8 weeks 10 m above (solid bar on the left) and 30 m below (hashed bar on right).

Typical FCR in *O. niloticus* cage aquaculture systems in Africa is between 1.4 and 2.5 (Beveridge 2004; Personal Communications, Patrick Blow, Lake Harvest Aquaculture, Zimbabwe, October 2006; Steve Murad, Tropo Farms, Ghana, November 2008; Karen Veverica, FISH Project, Uganda, January 2009). The higher than usual FCRs realized at Dzemeni are presumably the result of a high percentage of fines in the feed and possible variability in its proximate analysis, coupled to the $\pm 40\%$ over-estimation of the number of fish in each cage as a result of undetected mortality, and thus over-feeding. If the Akosombo strain of *O. niloticus* used in this study has the physiological capacity to achieve a mid-range FCR of 1.6 (Beveridge 2004), then an average of 47% of the feed inputs to the cages was wasted. At an average of 52% of total production costs, a 47% savings in feed would add an additional ₪700 to the bottom line, substantially improving the economics of the system.

Although only about half of the fish reached the target size of 300 g, the overall average specific growth rate of 1.8% body weight per day (mixed sex; virtually unlimited feed) compares favorably with the 1.5% body weight per day calculated from a range of intensive caged tilapia grow-out trials reported by Balarin & Haller (1982) and El-Sayed (2006), 1.1% realized in low-volume/high-density cages stocked with mixed sex *O. niloticus* in Uganda (Personal Communication, Karen

Objectives CPWF Project Report

Veverica, FISH Project, Uganda, January 2009) and even the 2.2 percent per day for all male fish produced at Lake Harvest (Personal Communication, Patrick Blow, Lake Harvest Aquaculture, Zimbabwe, October 2006).

Despite the difficulties encountered, the technical feasibility of the cage culture system was successfully demonstrated. The cages proved sufficiently robust to survive most of the prevailing natural conditions in the Volta Lake, although one of the cages was damaged by floating tree debris, a risk that should be further evaluated. Acts of vandalism and theft are a further risk to which fish cages are sometimes subjected. Prevalence varies with prevailing socio-cultural and economic conditions, governance and the type of development – e.g. scale, equitability of benefits sharing, impacts on livelihoods of other stakeholders. If the causes can be understood it may be possible to mitigate their impact (Beveridge 2004). According to the data collected at Dzemeni, a minimally profitable 48 m³ small-scale cage aquaculture system in Ghana would have to produce at least 1 tonne of fish at an FCR of less than 2.5. With WRI technical assistance, some 20 small-scale investors in the lower Volta River basin are at the time of writing (May 2009) applying the cage aquaculture technology tested at Dzemeni (Photo 1.3).

During the first trial, 4,990 kg of feed were added to the ecosystem, with no detectable effects of cage aquaculture on water quality in the vicinity of the production site. The lack of any clear correlation between water quality parameters that might be expected to fluctuate together (e.g., dissolved oxygen and nitrogen, electrical conductivity and turbidity) implies that external influences such as currents, localized flooding events, seasonal water level declines, *inter alia* seem to have an over-riding influence on the parameters measured at the production intensity tested. Such observations have often been made in the vicinity of small cage developments.



Photo 1.3. Example of small scale cage trials being implemented by individuals in the lower Volta River

At higher density, however, cages will undoubtedly have impacts on water quality, indicating the need for careful site selection and ultimately some type of zoning system for cage aquaculture in the Volta Lake and monitoring to support an adaptive management system.

1.2.3. Cage Culture and pens in the Indo-Gangetic Basin

Choice of sites and fisheries enhancement models in the Indo Gangetic Basin

In India, reservoirs are recognised as sleeping giant for fisheries development with their large expanse (3.15 million ha) and vast untapped production potential. The Indo-Gangetic Basin (IGB) has 1.16 million ha reservoir area (37% of total Indian reservoirs). The exploitation level of these waters is much below the potential due to traditional methods of fishing and non-adoption of methods for improving production (Sugunan, 1995). Fish yield enhancement in these reservoirs is possible with low capital investment and practically negligible environmental degradation through culture-based fisheries interventions. Enhancement options include stocking species of commercial value and habitat enhancements. Such enhancements will directly benefit poor traditional fisher communities, especially in the surroundings of the reservoir.

In the IGB, the project objectives required that the sites be identified after careful evaluation of the expectations and the need of local stakeholders. In contrast to the other two basins, where the sites were pre-determined (Lake Nasser in the Nile Basin and Lake Volta in the Volta Basin), it was therefore necessary to screen a large number of reservoirs in the IGB, before finally narrowing down to two sites.

Pahuj reservoir (518 ha) in Jhansi district of Uttar Pradesh and Dahod reservoir (460 ha) in Raisen district of Madhya Pradesh were the two reservoirs selected, as they belong to small category of reservoirs and considered as the representative for the reservoir offering potential for fisheries development. Amongst all possible options for fisheries enhancement⁶, two technically viable models were considered in consultation with the stakeholders⁷. Those were (i) seed stocking (species composition of fish seed, direct stocking of fish seed, installation of cage and pen units to raise the required size of seed for reservoir stocking) and (ii) improvement of the institutional arrangements (fishing regime and practices, leasing mechanisms, fish production and marketing institutions, credit, social and institutional support, etc.) and infrastructure of fish marketing and transportation.

Details of the fisheries enhancement tools and strategies included in the component (i) were finalized through (a) technical assessment of water quality and fish production potential (implementation of physico-chemical tests for water quality of reservoirs and biophysical assessment of plankton, benthic and macrophyte communities), and (b) consultation and discussions with the local stakeholders on social, institutional, production and marketing issues. The interventions related to the component (ii) around marketing institutions are presented in section 3 of this report.

The potential yield of the two project reservoirs was estimated at 285 and 312 kg ha⁻¹ at Dahod and Pahuj, respectively. As per previous records, a maximum of 17% of this potential in case of Dahod and 40% in case of Pahuj was being harnessed. Based on this information the project targeted to achieve a fish yield in the range of 100 to 125 kg/ha in both the reservoirs through appropriate scientific intervention.

Methods

Enhancement Strategies

To achieve the targeted fish yield, strategies on habitat, stock and species enhancements were formulated.

Habitat enhancement: Prior to intervention, both reservoirs had significant coverage of aquatic macrophytes that impacted negatively on the fish yield. In case of Dahod reservoir, stocking of *C. idella* (Grass carp) was one of the strategy to reduce the weed infestation. In Pahuj reservoir, fishing activities had been suspended during pre-project period (2005-06 and 2006-07)⁸ since the FSD did not permit any individual or cooperative to harvest the stocks due to administrative reasons. In this process the reservoir became weed choked, resulting in a significant increase in the population of minnows. With the initiation of the project the concerned FSD permitted the operation of commercial fishing under the overall technical supervision of CP34's partners. These interventions resulted in bulk harvest of minnows and clearance of macrophytes. With these activities the habitat becomes slowly congenial for carp fishery. Additionally, a shift in fish species in favor of commercially important fishes was noticed following the stocking intervention implemented by the project (see below).

Stock enhancement: The existing fish yield was much lower than the estimated potential, suggesting stock enhancement in both reservoirs. Based on the gap between the actual and targeted fish yield, the stocking rate was decided on the basis of anticipated targeted production and general growth rates of targeted species under reservoir conditions. Accordingly the rates

⁶ The major possible interventions for viable enhancement model considered in this case were: i) improved stocking practices (number, size, composition and time of stocking); ii) production of desired quality stocking material in pen/cages after collection of natural/artificially bred spawn; iii) fish harvesting practices and programme (type of fishing gear and craft, minimum size and weight of fish caught, closed season, lean, medium and peak season of harvesting, etc.); iv) optimum fish marketing practices (storage and transportation facilities, processing, direct and efficient fish disposal pattern); v) more interactions and better understanding among stakeholders; and vi) improved institutional arrangements and co-management for higher equity and access for fishers.

⁷ Stakeholder Consensus Building Workshop No.2 (20 June 2006) –see Table 3.1 below.

⁸ The reservoir could not be leased out due to drastic reduction in water level and inflow of domestic sewage and deterioration of the aquatic environment of the reservoir.

Objectives CPWF Project Report

were estimated at 435 and 386 advanced fingerlings ha⁻¹ for Dahod and Pahuj reservoir, respectively. The stocking protocol implemented involved both direct seeding of fingerlings from local fish seed farms and fry raised in cages up to advanced fingerling stage. In the case of Dahod reservoir, out of 0.17 million fingerlings stocked, 60% fingerlings were procured from farms, while the remaining 40% fingerling was raised in the cages. For Pahuj reservoir, out of 0.2 million fingerlings, 70% fingerlings were procured from farms and the balance was raised in cages.

Species enhancement: Another way of improving the productivity is through increasing the share of commercially important fish species in the total catch through species enhancements. The Indian major carps are preferred species in the country and command a much higher price in comparison to other species. Thus a strategy to improve the percentage of Indian major carps (Catla, Rohu and Mrigal) was planned in both reservoirs. The previous data of 1995-96 indicated that these species contributed only 5-8% of the total catch in both reservoirs. In Dahod the species composition of stocked fingerlings was 45% *C. idella*, 10% *C. carpio* (common carp) and 45% Indian major carps, while it was respectively 25%, 10% and 65% for the same species in Pahuj reservoir. This composition was decided based on the level of macrophyte infestation in each reservoir and harnessing of detritus through common carp.

Raising of fingerlings in cages

Availability of appropriate fish seed in time and space is one of the main constraints in reservoir fishery development. To overcome this problem, fingerling were raised from fry (18 mm average length) in situ in cages at both reservoirs. The results are highlighted below:

Cage experiment in Dahod: In the first phase, one battery of eight cages was installed in the reservoir (Photos 1.4) with each cage of 5 m x 3 m x 3 m dimension. The cages were stocked with 90,000 (*C. idella* - 54,000, *C. carpio* - 36,000) fish fry (20-22 mm size). After a rearing period of 105 days 45,240 fingerlings (survival - 50%) were released in the reservoir. The stocking size and weight of *C. idella* was 70-96 mm and 5.0-11.0 g respectively, while for *C. carpio*, it was 85-112 mm and 19-26 g respectively.

In a second phase, two batteries of eight cages each were installed. In three cages 36,000 Indian Major Carp fry of 30-34 m size (*L. rohita*: *C. catla*: *C. mrigala* = 5: 2: 3) were released. After a rearing period of 150 days 23,322 fingerlings (survival - 64.78%) were recovered and stocked in the reservoir (Photo 1.5 left). The stocking size and weight for different species was: *C. catla*: 90-150 mm and 19-32 g, *L. rohita*: 88-160 mm and 15-28 g and *C. mrigala* 82-130 mm and 12-23 g. In the remaining 13 cages 140,000 fry of *C. idella* (40%) and *C. carpio* (60%) were raised to fingerlings. After a rearing period of 160 days, 107,693 fingerlings (survival - 77%) were released in the reservoir. The stocking size of *C. idella* was 98 mm in length and 3-10 g in weight as compared to *C. carpio* 72-110 mm in length and 10-21 g in weight.



Photos 1.4. Cages being installed on the Dahod (left) and Pahuj (right) reservoirs.

Cage experiment at Pahuj: In Pahuj reservoir one battery of eight cages (each cage size 5m x 3m x 3 m) was installed and 100000 fry (*C. idella* 74% and *C. carpio* 26%) were released (Photos 1.4). The length of fry at release was 16-28 mm. After a growing period of 145 days 62,400 (survival - 62.4%) fingerlings were released in the reservoir. The stocking size for *C. idella* was 65-96 mm in length and 4-12 g in weight. For *C. carpio* stocking size in length was 74-115 mm and in weight was 12-22 g.



Photos 1.5. Left: fingerling raising in Cages in Pahuj reservoir. Right: a harvest of major carps at Pahuj reservoir being examined.

Impacts of the intervention

The impact of interventions made was assessed in terms of increase in fish production of targeted species and their percentage increase in total production. Besides, fishing intensity (number of fishers and fishing days) was also monitored and included in the assessment. The information on fish landings and fishing efforts was gathered from landing sites and records of respective SDFs. To assess the impact more clearly these parameters were compared in time scale and for pre and post project period.

Dahod

At the time of writing this report (May 2009) it is the second year of the fisheries enhancement interventions under CP34 and the impact is thus only available for one year. The project activities have increased the fish production of the reservoir from 17.50 to 22 t (Table 1.19).

Table 1.19. Impact of interventions on fish catch of Dahod reservoir

Fish category	Fish catch(in t)			% increase over pre-project	Fish catch (in %)		
	1995-96	Pre (2006-07)	Post (2007-08)		1995-96	Pre (2006-07)	Post (2007-08)
Major carps	1.34	5.47	11.14	103.66	8.74	31.25	50.52
Catfishes	4.44	5.35	4.98	-6.92	28.98	30.57	22.56
Miscellaneous	9.54	6.68	5.93	-11.23	62.28	38.18	26.86
Total	15.32 (18.0)	17.50 (20.0)	22.06 (22.0)	26.06	100.00	100.00	100.00

(Figure in parentheses is the targeted quota fixed by the Department of Fisheries)

Objectives CPWF Project Report

The data set reveals that during 1995-96 the production of major carps was only 1.34 t and contributed only 8.74% of the total catches. During the ten year period (1996-97 to 2006-07) during which some stocking programme initiated by the SFD took place, the production of major carps increased to 5.47 t contributing 31.25% to the total catches. After the project intervention the production of major carps increased to 11.14 t -increasing the percentage contribution to 51% in the total catches.

It should be recalled (*cf fisheries status* in section 1.1.1) that a system of fixed quota has been imposed by the SFD in the region concerned by the project. In particular, for 1995-96 a quota of 18.0 t had been fixed on Dahod reservoir. During the pre-project period (2006-07) the target quota had been increased to 20.0 t. Note however that in both periods (1995-96 and 2006-07) the actual total production did not reach these quota (but only 15 t and 17.5 t respectively) –see Table 1.19. In contrast, during the project period (while the fixed quota had been raised further to 22 t) the total harvest reached the quota after only 3 months. It seems reasonable to assume that, had there not been any fixed quota, the fishing could have continued and higher catches and production achieved.

Despite this fixed quota, the project data does reflect increased percentage in major carps. In particular, much more increase has been registered during the project period in comparison to previous ten years (Table 1.19). Since the major carps yield better price their higher percentages resulted in better returns per kg to fishers in spite of fixed quota policy. The outcomes of interventions will be more pronounced with time, as impact of regular stocking, species and habitat enhancements will be visible through better fish harvests in future. The result promises important scope for fisheries enhancement and other institutional interventions for both scaling up and scaling out. Recognizing the impact of the project, SFD put forward a massive plan for implementation of these interventions in most of the reservoirs of the state.

Pahuj

In Pahuj reservoir, impact of interventions on the fish production and composition were analyzed and a trend of positive impact was noticed for both the production and composition of fish catch. Looking back at the 1995-96 period, SFD data indicate that major carps was characterized by a poor production of only 0.06 t, that is, a contribution of 0.44% in total catches, while minnows were contributing 96% (13.03 t) of the total catch. In subsequent years (except for occasional stocking of major carp seed by the department) no appropriate management plan was implemented.

With fishing suspended in the reservoir for two years prior to its adoption under the project the huge biomass of minnows accumulated. As a part of habitat enhancement action plan, this biomass was partially harvested, yielding 300 t of minnows during 2006-07 in two phases. It may be mentioned here that for the implementation of this project the state authorities permitted the contractor/lessee to fish in the reservoir in consultation with project. After the clearance of weeds and minnows, the reservoir became quite favorable for growth of economic fish species.

Table 1.20. Impact of interventions on fish catch of Pahuj reservoir

Fish category	Fish catch(in t)			%	Fish catch (in %)		
	1995-96	Pre	Post*		increase	1995-96	Pre
Major Carps	0.06	6.62	32.39	389.26	0.4	25.40	50.56
Minor carp	0.27	4.97	4.22	-15.06	2	19.07	6.59
Catfish	0.13	2.49	15.56	524.91	0.96	9.55	24.29
Minnows	13.03	11.98	11.89	-0.76	96.4	45.97	18.56
Total Production	13.52	26.06	64.06	145.82	100	100	100

* catch only for March-June

Based on the biophysical analysis, a phased stocking programme was implemented. The major carp catch during CP34 implementation increased to 32.39 t to a total production of 64 t registering 51% contribution of major carps. This contrasts sharply with the pre-project year

during which the contribution of major carp in was only 6.62 t (25% of the total production of 26 t). In comparison to Dahod reservoir, there is no fixed quota policy for fishing in Pahuj. Thus in the case of Pahuj the positive impact of the project was its contribution in shifting a low economic reservoir (dominated by minnows) to higher economic reservoir with major carps contributing 50% to productivity and overall increase in reservoir catch to 64 t.

Overall, data indicates an increment of over 145% in catch. The maximum percentage increase was for catfishes followed by major carps. But the scientific stocking did positively contribute to the increment in catch of major carps was 389%. Considering the wide gap between existing and potential fish production in the reservoir, regular stocking of carps is expected to improve further their production and contribution in total catch significantly.

1.2.4. Fish enclosure in the Nile Basin

Choice of sites and fisheries enhancement models in the Nile Basin

In the Nile Basin, the focus of the project was on the Lake Nasser. Several series of discussions were organized with the main stakeholders of the fishery to identify potential options for enhancement. It should be noted here that the Lake Nasser is a very specific case in that respect. Due to the role that it plays as main source of drinking water for the population of Cairo, no exotic species can be introduced and no artificial feed or fertilizer can be used, limiting the types of enhancement options that could be envisaged.

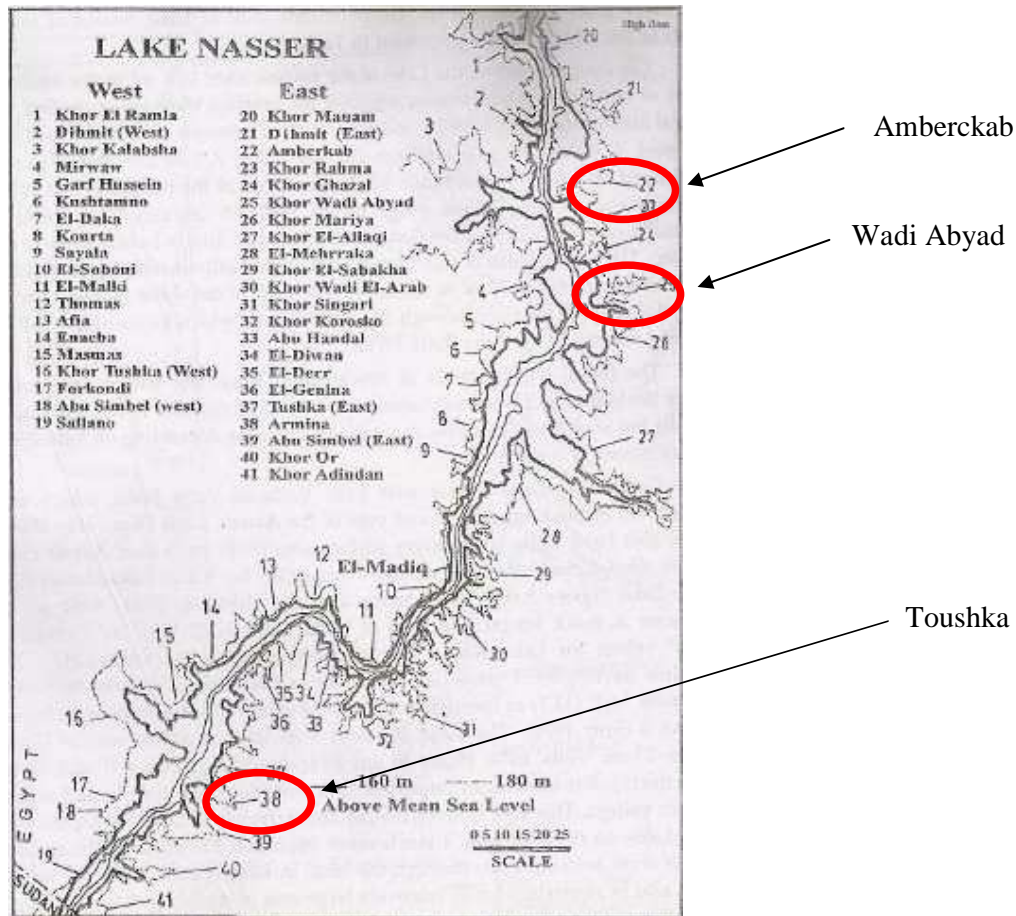


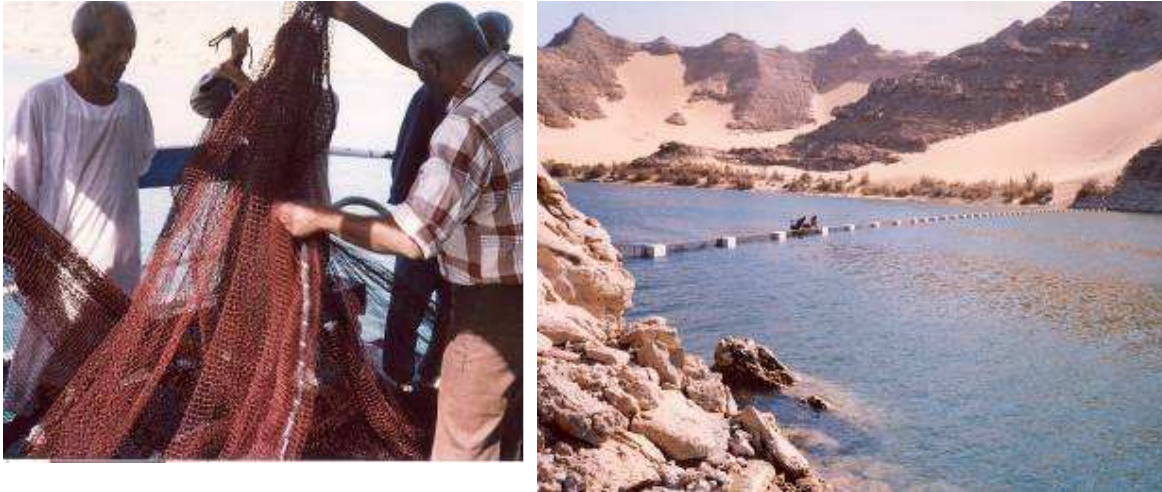
Fig.1.19. Location of the three khors where enclosure experiments were conducted

Objectives CPWF Project Report

After discussion and consultation with the stakeholders, it was decided to engage in the stocking and management of fish enclosures established inside some of the lake's *khors*⁹. Three *khors* amongst the 41 existing along the shores of the lake were selected (Tushka, Ambercab, Wadi Abyad) (Fig.1.19) where the enclosures would be established and agreement was achieved with the owners of the *khors* regarding the succession of tasks to be completed.

Methods

The three enclosures were established during March 2007. For each of them a net was set up across the entrance of the *khor* (Photos 1.6 and Fig.1.20). The first batches of 200,000 *Oreochromis niloticus* fingerlings (average weight of 15 g) were released in May and June 2007 in each of the enclosures (total number of 600,000 fingerlings).



Photos 1.6. Installation of the net in the *khor* entrance.

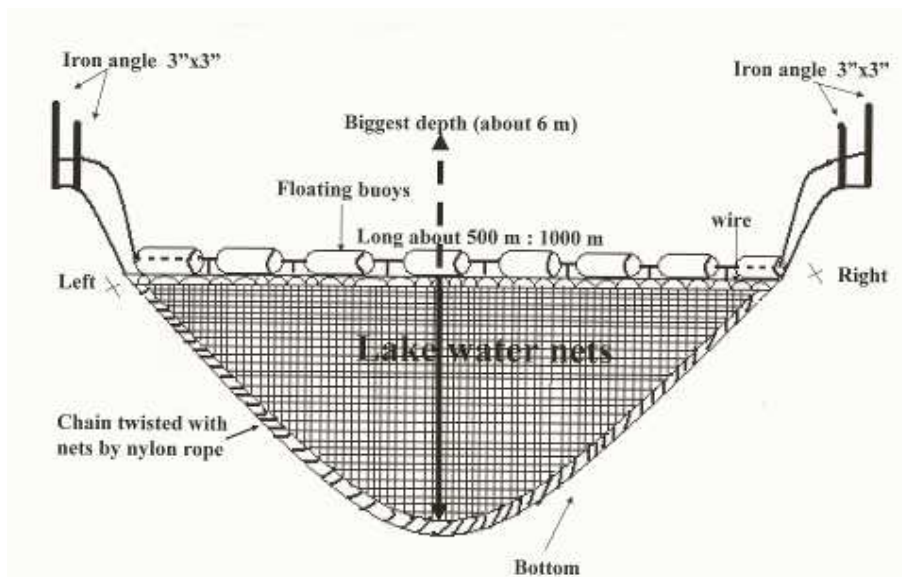
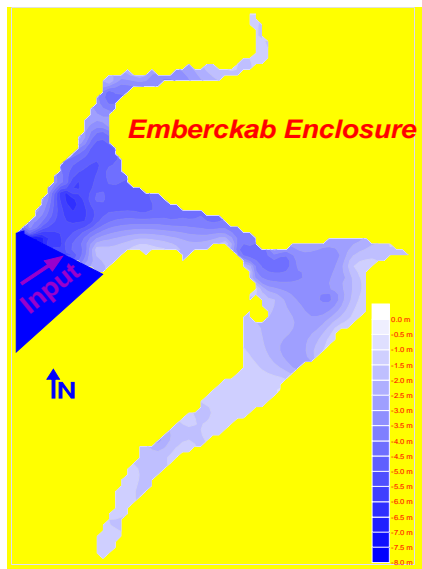


Fig.1.20. Vertical section of the net used for enclosure

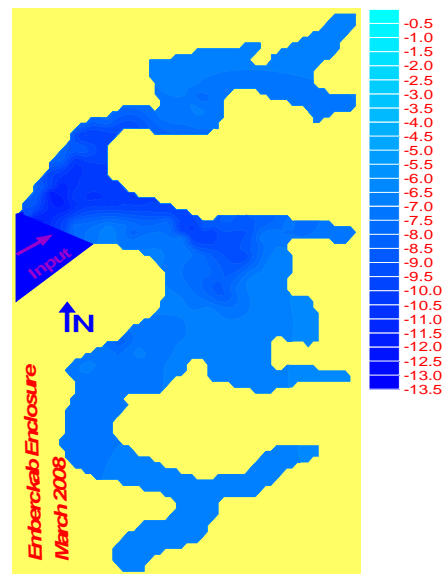
⁹ Workshops organized on 19-20 Sept. and 14 Nov. 2006 –see Table 3.1 below. Four Cooperative Societies, three Investors' Companies, Investment Society for Fish trader and representative of Chief Fishermen attended the workshop. Representatives of stockholder groups and local Administrative authorities were gathered to discuss different aspects of lake fishery management and obstacles to improve production.

Simultaneously, the systematic removal of Nile perch and *Hydrocynus forskalii*) was implemented with the objective to decrease the predator fish inside the enclosures. In September and October 2007 the second batch of 2,000,000 *O. niloticus* fry (average weight of 2-5 g) was released in Amberckab and Wadi Abyad - one million each. The third enclosure was kept unstocked as a blank experiment for comparison. From the third patch of fry, which released on November 2008, about 400,000 *O. niloticus* were kept in a small nursery inside Wadi Abyad enclosure.

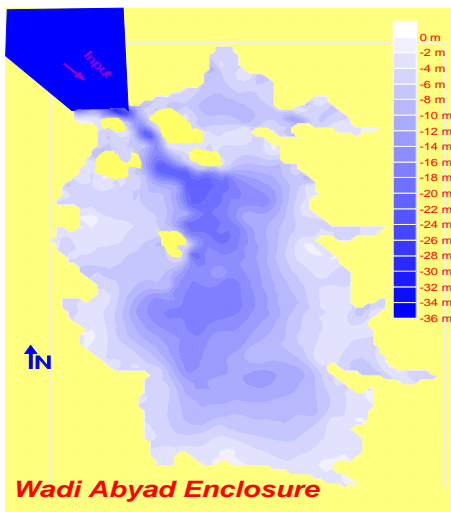
The objective of the predator's removal was to eliminate or decrease the carnivorous fish from the enclosure before releasing *O. niloticus* fingerlings. The predators were fished out using bottom gill nets with stretched mesh size of 13 cm and 16 cm in Ambercab and 12, 14 and 20 cm mesh size in Wadi Abyad. In addition longlines were used in both enclosures. The predator removals were carried out from April 2007 to March 2009 (109 fishing days) at Ambercab enclosure and from mid May to early August 2007 (49 fishing days) at Wadi Abyad enclosure.



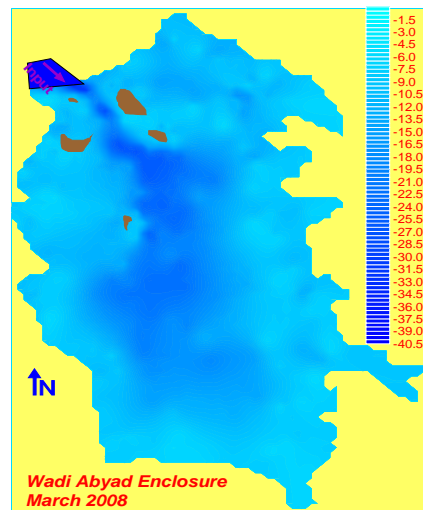
Bathymetric chart of Emberckab - summer



Bathymetric chart of Emberckab - winter



Bathymetric chart of Wadi Abyad - summer



Bathymetric chart of Wadi Abyad - winter

Objectives CPWF Project Report

Fig.1.21. Water Depth and Surface Area of two enclosures at two water levels

A single set of experimental fishing inside the enclosures (5 days in Ambercab and 7 days in Wadi abyad) was carried out in March 2009 by fishers from the project, using trammel gill net with different stretched mesh size (10, 12, 14 cm) to obtain the size composition and to get basic information about the fishing effectiveness. The body length and body weight for each fish was measured by species. In addition, the local fishers inside Ambercab were asked to measure their catches by length starting from end of March 2009.

Data and water samples from the two Lake's enclosures were collected during July 2007 (low water level), and March 2008 (high water level). The outer boarder charts of the two enclosures were performed using 2571 shoreline positions. Bathymetric chart for the two enclosures are shown in Fig.1.21. Emberckab enclosure water depths fluctuated between 7.6 m (maximum depth in summer) and 13.4 m (maximum depth in winter). Wadi Abyad enclosure water depths fluctuated between 35.1m (maximum depth summer) and 40.1m (maximum depth winter). The surface water area of Emberckab enclosure increased from 0.28 million m² in summer to 1.27 million m² in winter. The surface water area of Wadi Abyad Enclosure increased from 2.11 million m² in summer to 2.13 million m² in winter.

Fishing activities inside the enclosures by local fishers began in May 2008 and May, June 2008 at Ambercab and Wadi Abyad respectively. It was stopped after one fishing trial at Ambercab (4 working days) and 4 trials (25 working days) at Wadi Abyad due to low fish catch. There are two fishing boat with four fishers in both enclosures. The commercial fishing was resumed in January 2009 and stopped again by the middle of April 2009 (due this time to the closed fishing season in Lake Nasser). The 2009 fishing consisted of 11 and 7 fishing trips for Ambercab and Wadi Abyad enclosures respectively.

Unfortunately, the data collected from the non-stocked control enclosure at Tushka was not in a format that allowed for calculating catch rates or species composition, and has therefore been omitted from this analysis. The data and results presented below should be seen as preliminary results. More work and data are needed to judge and evaluate the enclosure model as tested in this project.

Results

Removal of predators

The predators composed of *Lates niloticus*, *Hydrocynus forskalii* and *Bagrus bayad* at Ambercab enclosure. *Malapterurus electricus* was also caught during the removal of predators. The total catch was 774 kg from April 2007 to July 2008. *Hydrocynus forskalii* recorded the highest percentage of 56.1 among the predators followed by *Lates niloticus* of 41.9% through the whole period. The total catch of the predators declined from 418 kg in April to 2 kg in December 2007. Fifteen crocodiles were also caught inside the enclosure with different size ranged from less than 2 m to more than 3 m.

In case of Wadi Abyad enclosure, the removal of predators took place from Mid May to Early August 2007. The total catch was 411 kg and consisting of *Lates niloticus*, *Bagrus bayad* and *Hydrocynus forskalii*. Other species were recorded during the predator removal such as *Synodontis schall*, *Tetradon fahaka*, *Clarias Lazera*, *Malapterurus electricus* and *Mormyrus kannume*. A declining trend in the catch rates was observed during the period (Fig.1.22). *Lates niloticus* was the most abundant predator with 36.9% followed by *Bagrus bayad* of 24.7%. Two crocodiles of 3 m body length were caught and a large size monitor lizard with body length of 45-65 cm was recorded too.

Releasing of *O. niloticus* fingerlings and fries

The initial average weight of the fingerlings was 15 g and the final weight ranged from 80 g to 260 g on the middle of March 2009. This means that the increment weight ranged from 65 g to 245 g through 135 days (average 1.3 g day⁻¹).

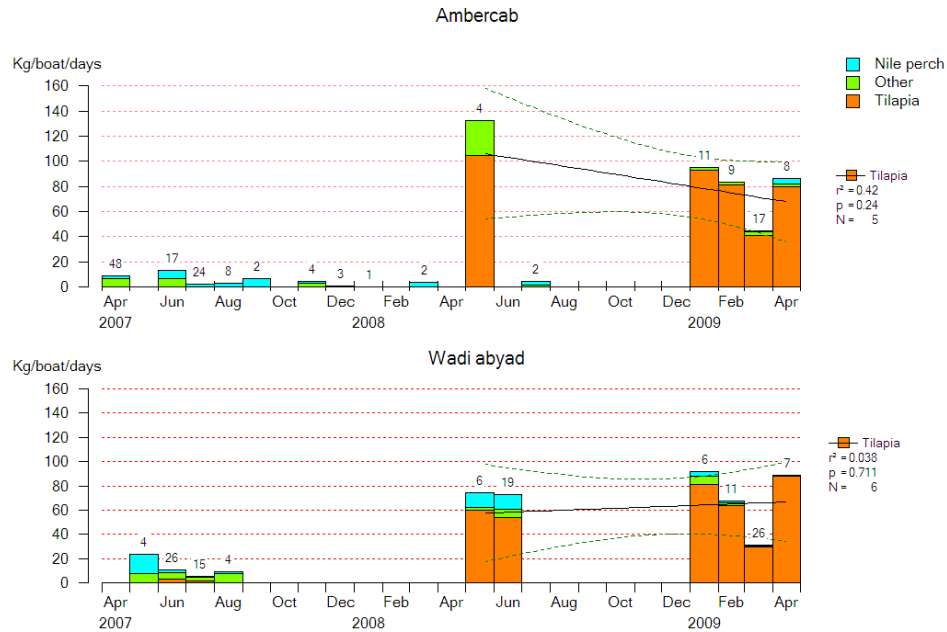


Fig.1.22. Mean monthly catch per unit effort (kg boat⁻¹ day⁻¹) inside two enclosures for the period of the experiment. Numbers are days fished month⁻¹

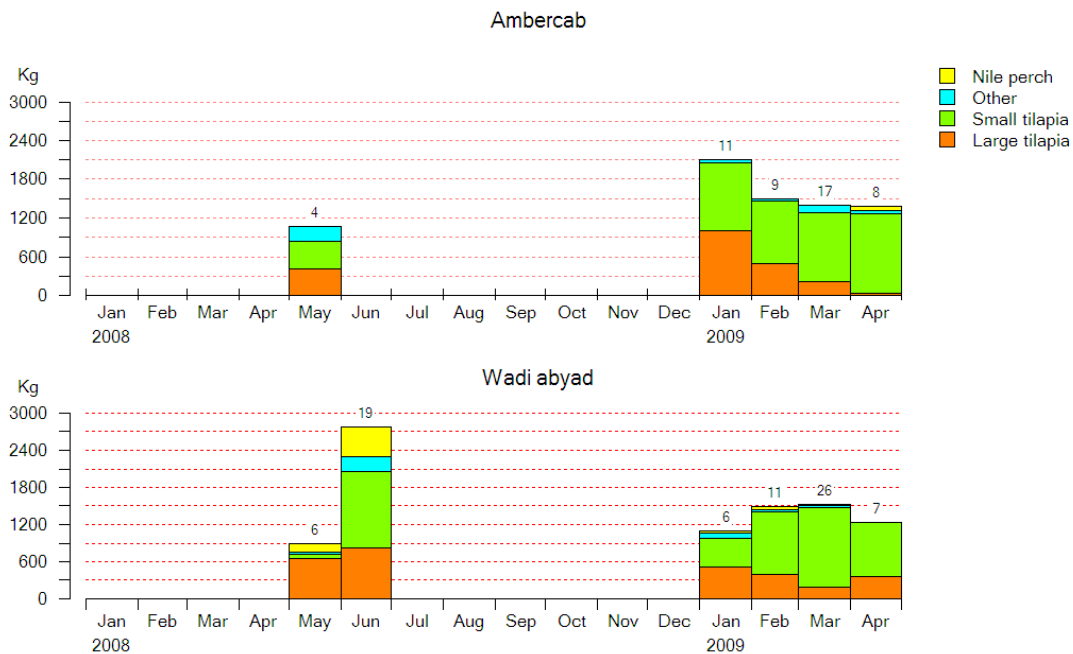


Fig. 1.23. Total monthly catches (kg) by small (< 1 kg) and large (> 1 kg) tilapias, Nile perch and 'others', inside Ambercab and Wadi abyad enclosures. Numbers are days fished month⁻¹.

Fish catch

Catch per Unit Effort (CPUE) was calculated as kg boat⁻¹ day⁻¹ for both enclosures (Fig.1.22). CPUE at Ambercab enclosure ranged from 133 kg boat⁻¹ day⁻¹ in May 2008 to 52 kg in March 2009. At Wadi abyad it ranged from 67 kg boat⁻¹ day⁻¹ in June 2008 to 92 kg boat⁻¹ day⁻¹ in January 2009. The total catch at Ambercab and Wadi Abyad is shown in Fig.1.23. The species composition

Objectives CPWF Project Report

of the catch was Tilapia (separated into large > 1kg, and small < 1kg), *Lates niloticus* and 'others'. The majority of the 'small' tilapia is the non-stocked *Sartherodon galilaeus* (see below).

Experimental fishing

As expected, the highest numbers of fish were collected by the 10 cm mesh size net (Fig.1.24) for all the fish species with average body length of 25.6 cm (16.5-51.0 cm) with average body weight 541.1g (100-2340 g). The 12 cm mesh size net collected fish with average body length of 30.4 cm (20.5-70.0 cm) and average body weight of 887.5 g (180-3000 g). The average recorded body length of all fish caught by the 14 cm mesh size was 33.0 cm (21.5-48.0 cm) with average body weight of 1159g (320-2520 g). The data of the experimental fishing were compared with the commercial fishing inside Wadi abyad using 12-14 cm mesh size. The mean body length of the commercially fished Tilapia was 24.4 cm.

The maximum number of *O. niloticus* collected by 10 cm net with average body length 27.6 cm (20.0-41.0 cm) and the average body weight was 702 g (120-2340 g). The 12 cm mesh size net caught the second maximum of *O. niloticus* with average body length of 29.6 cm (24.0-39.0 cm) with average body weight of 853 g (380-1760 g). In case of the 14 cm mesh size net, the average body length recorded was 32.9 cm (23.5-44.5 cm) with average body weight of 1145 g (340-2320 g).

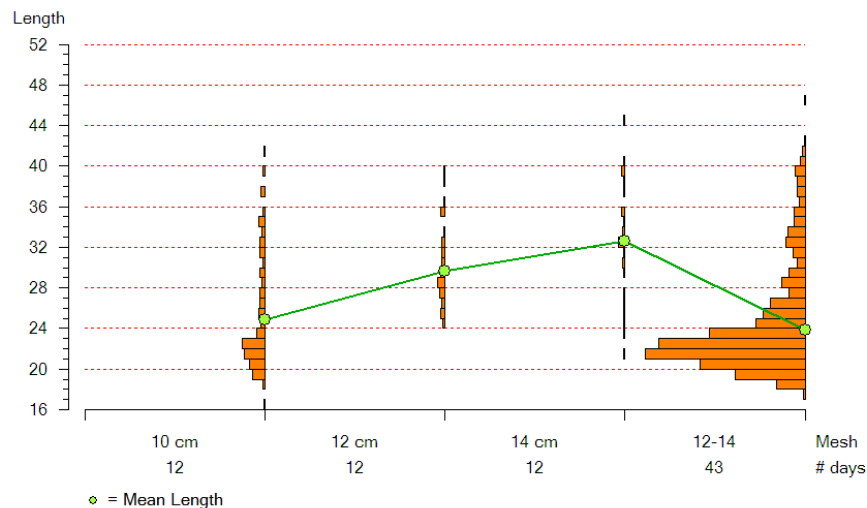


Fig.1.24. Frequency distribution of body length of tilapia species by different mesh sizes

In case of *Sarotherodon galilaeus* all the fish were caught by the 10 cm net with average body length 20.6 cm (16.5-25.5 cm) and average body weight of 307 g (100-440 g). Only one fish with 21.5 cm body length (320 g) was collected by the 14 cm net, but no *Sarotherodon galilaeus* were recorded for the 12 cm experimental net. However, the majority of the measured fish (774 out of 988) in the 12-14 cm commercial gillnets inside Wadi abyad were *Sarotherodon galilaeus*.

Length-weight relationship of *O. niloticus* at enclosures

The relationship between body length and body weight of *O. niloticus* is shown in Fig1.25 and Fig.1.26 for Ambercab and Wadi Abyad enclosure for all the data of experimental fishing with different mesh size (10, 12 and 14 cm) plus the samples collected by the commercial fishers.

These curves are the function of

$$W = a L^b$$

where W is the body weight (g), L is the body length (cm), and a, b are parameters. The length weight relationship of *O. niloticus* and *S. galilaeus* inside enclosures were estimated as follows:

$$O. niloticus \quad W = 0.045 L^{2.912}$$

$$S. galilaeus \quad W = 0.270 L^{2.35}$$

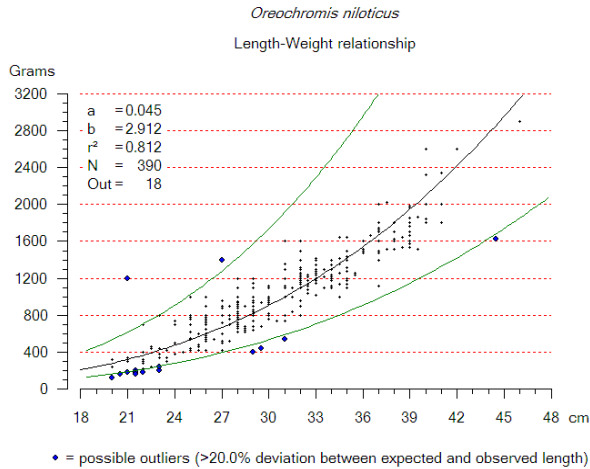


Fig.1.25. Length – Weight relationship of *O. niloticus* inside enclosures

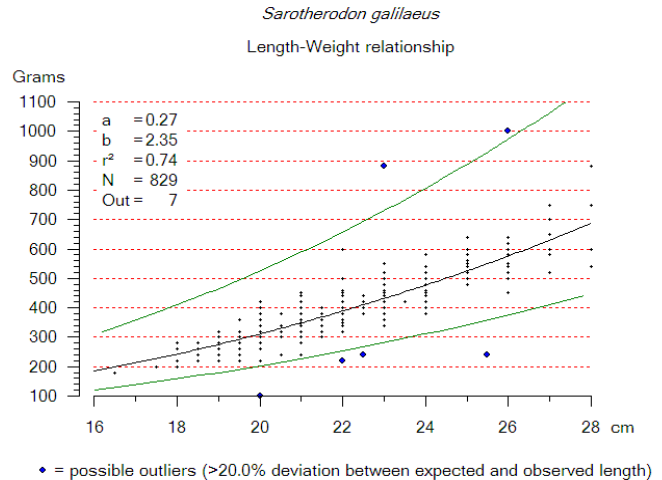


Fig.1.26. Length – Weight relationship of *S. galilaeus* inside enclosures

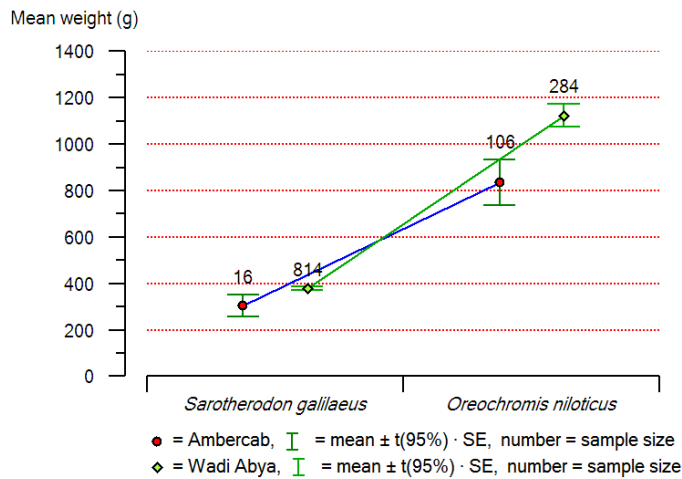


Fig.1.27. Mean body weight (g) of *O. niloticus* and *S. galilaeus* inside enclosures

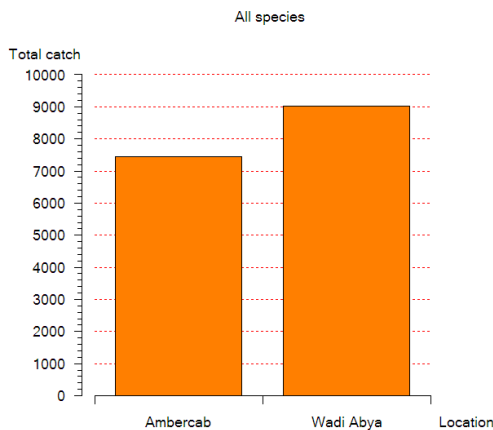


Fig.1.28. Total catch (kg) for all species inside the enclosures

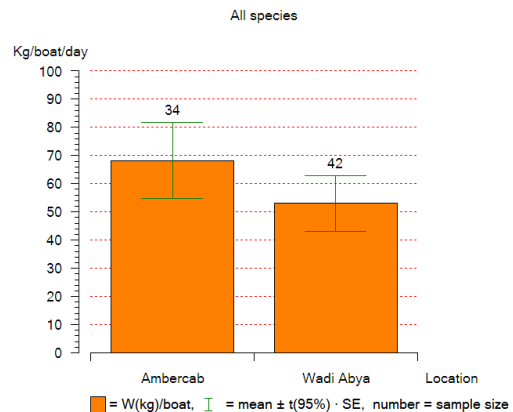


Fig.1.29. CPUE (kg boat⁻¹ day⁻¹) for all species inside the enclosures

Fig.1.27 shows the mean weight of individually measured specimens of *S. galilaeus* and *O. niloticus* at Ambercab and Wadi Abyad separately. At Ambercab enclosure the mean body weight

Objectives CPWF Project Report

of *S. galilaeus* was 305 g while it was 379 g at Wadi Abyad enclosure. Mean weight of *O. niloticus* in Ambercab was 835 g and 1124 g at Wadi Abyad.

Fish catch inside enclosures

The total catch for all species inside Ambercab and Wadi Abyad enclosure was drawn separately for the entire fishing trail during 2008 and 2009 (Fig.1.28). Wadi Abyad enclosure recorded 10200 kg while Ambercab recorded 7400 kg. Also, the total average CPUE (kg boat⁻¹ day⁻¹) for each of the two enclosures were calculated as shown in Fig1.29. The Ambercab enclosure yielded a slightly higher average CPUE of 84.9 kg boat⁻¹ day⁻¹ compared to Wadi Abyad with 82.1 kg boat⁻¹ day⁻¹.

Fish catch outside enclosures

In Lake Nasser carrier boats operate within each location, collecting the fish from an assigned area from groups of fishers on regular basis. All of the collected fish are landed at different harbors in Aswan, Garf Hussein and Abu Simbel. Two of these carrier boats cover the area outside Ambercab enclosures (El Mubarak serves 12 fishing boats and El Hamd Allah serves 35 fishing boats) while three carrier boats are working outside Wadi Abyad enclosures (Barakat serves 35 fishing boats, Abd El Naby serves 32 fishing boats and El Tayeb serves 17 fishing boats). Two fishers were working on each boat and using trammel gill net with 14 cm and bottom gill net with 12.5 cm. The total catch from inside and outside (covering the months January to April by year) the enclosures (by carrier boat) is shown in Fig.1.30. The total catch outside the enclosures are high compared to inside the enclosure, but they also cover a larger area.

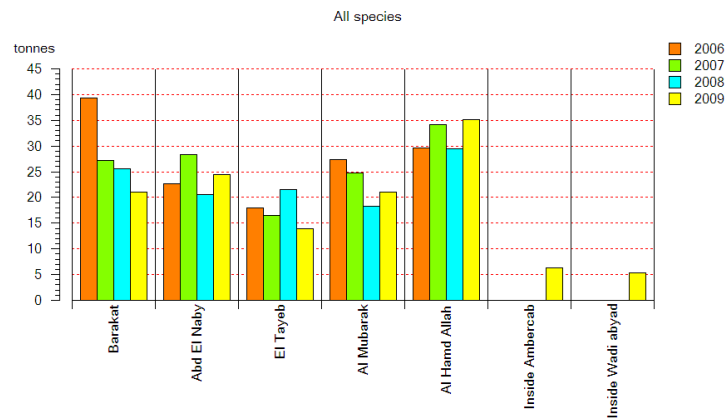


Fig1.30. Total catch (ton) for all species outside and inside enclosures during months of January to April by year.

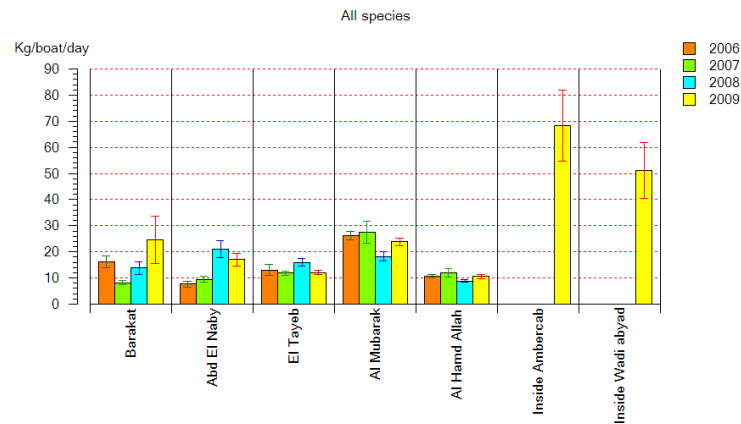


Fig.1.31. CPUE (kg/boat/day) for all species outside and inside enclosures during months of January to April by year.

Fig1.31 shows the CPUE ($\text{kg boat}^{-1} \text{ day}^{-1}$) for inside and outside enclosure for the same set of data. It is clear that the CPUE inside enclosure are higher than outside the enclosures, but they also represent a lower effort per unit area than outside with approximately 1 boat per km shoreline.

It should be mentioned that both inside and outside are using the same length of net (100 m) but different mesh size. The mesh sizes used inside the enclosures are legal in contrast to the mesh size used outside. This means that most of the fish collected outside are smaller than the fish from inside enclosures.

Concluding remarks on Lake Nasser enclosures

At present it is difficult to draw any firm conclusions of the effectiveness of the enclosures as implemented in this first experiment. While catch rates (fish density) are higher inside the enclosures, the total yields (production) are higher outside. However, as the fished areas and the total effort allocation are not comparable between inside and outside, it is at present not possible to determine whether the observed differences are a result of enclosure treatments (predator removal and/or stocking), or just reflecting different fishing effort. In the continuation of the experiment a more detailed monitoring is needed. In particular the results will need to be standardized on an area, effort and time basis.

1.3. Section 1's General Discussion

In India field work emphasized the importance of understanding nutrient dynamics and matching them to the known feeding preferences of both indigenous and non-indigenous fish species. As indigenous riverine Rohu (feeding on phytoplankton in water column), Catla (feeding on zooplankton) and Mrigal (feeding on phytoplankton more benthic) cannot reproduce in the reservoir, their contribution to the catch -which was limited to those that entered from the river- only amounted to some 7% of the total catch. As these are the most popular and valuable species, boosting their percentage to 20% of the total was crucial in generating positive benefits. Basic biological and ecological data made this possible.

Working in the field rather than the laboratory also enabled researchers to fully appreciate the constraints facing local communities when trying to improve reservoir productivity. For many years, the larger sized fingerlings needed to stock reservoirs have been unavailable. The development of a practical method for growing them in situ in cages created a new investment option for those relatively low-income local stakeholders who can access at least US\$500 in capital to get started. At present, the major constraint to the further improvement of productivity may well be the government quota system. The latter was based on pre-project productivity. It needs now to be revised upward in light of the newly realized ability of local stakeholders to actively intervene in reservoir management to increase productivity.

In the Volta Lake, in light of the rapid gains witnessed over the project period in the productivity of cage aquaculture, the government of Ghana with the active engagement of CP34 researchers is already considering aquaculture zoning designed to ensure sustainability of this new activity. Based on a long consultative process with the local communities, both the ability to work successfully and the generation of information from researchers to potential technology users were facilitated. Problems associated with sabotage of the pilot trials were limited to a few disgruntled individuals. Being able to put local households in the position of local entrepreneurs seeking to improve their own fish sales and incomes, enable the design and piloting of practical technology.

The adaptation to local conditions and demonstration of practical cage aquaculture technology in Ghana, although a somewhat higher investment alternative compared to the nursing cages developed in India, nevertheless has engendered rapid adoption. With a capital requirement of about \$3000, a significant return on investment of more than 25% can be expected to generate proportionally higher impacts through the value chain.

In Egypt, efforts to improve productivity in Lake Nasser are particularly constrained by government policy vis-à-vis water quality. There are no possibility to introduce a pelagic species that might take advantage of a largely vacant niche for a pelagic planktivore, or to introduce feed-

Objectives CPWF Project Report

based aquaculture technology. Researchers instead engaged with local stakeholders to match knowledge of ecology to develop a practical system that combines known productivity patterns in the lake, stocking of preferred species and displacement of predators. While the preferences of local *chor* owners to wait in exploiting their managed stocks makes impact of these interventions difficult to gauge at the time of writing, further adaptation of the system and improved monitoring are being planned, assuring continued engagement of research with local stakeholders. Such collaboration can only improve the quality of data being collected about the fishery and the ability of researchers to intervene usefully on behalf of local fishers.

1.4. Section 1's Conclusion

Manipulation of reservoir ecosystems to improve productivity and outcomes for lower income communities is feasible, but to be realized, adaptive research needs to work closely with technology users to ensure that the rationale of the intervention and the technical details are fully appreciated by local stakeholders and, maybe more importantly, that research and extension come to understand the real opportunities and constraints confronted by potential investors.

Productivity in large reservoir ecosystems is intimately linked to the interplay between hydrology, nutrient dynamics and the fauna and flora which generate the services on which human communities depend for food and livelihoods. Large reservoirs are ecosystems in transition from riverine to lacustrine. The two large dam reservoirs studied in this project are about 50 years old and their fish populations remain in flux as species adapted to rivers evolve at both the biological and ecological levels into a more or less stable lake stock. Two major phenomena dominate this process: 1) relative competitiveness for altered food resources leading to the reduction or elimination of species that may once have been abundant and vice versa and, 2) the development of vacant ecological niches where no riverine species is able to take advantage of a new food resource. Most particular in this latter case are species that can capture and digest newly generated abundance of phyto and zooplankton, which are normally rare in rivers.

The introduction of species that might take advantage of underutilized food resources is constrained by the dangers associated with the introduction of non-indigenous species. In cases where this has been done, huge gains in productivity have often been achieved, but sometimes with dramatic loss of biodiversity. However, even in large reservoirs where exotic species introduction is not permitted, feeding and fish stock enhancement through release of preferred species either managed in enclosures and cages, or released for later capture in the fishery can also yield productivity increases.

In the present study, the reservoirs in the Indo-Gangetic Basin were the most amenable to manipulation, being relatively small and under strict government control with local management. Both cage aquaculture (nursing of small fingerlings to stocking size with artificial feeding) and the subsequent stocking of preferred (indigenous and non-indigenous) species resulted in gains both in quantity and value of the catch. The ability to match the stocking regime to available food resources was made possible by a quantitative and qualitative mastery of the nutrient dynamics of the ecosystem.

In the Volta Lake, both the size of the reservoir and government prohibition on the release of non-indigenous species limit the range of interventions to those involving localized habitat improvement (*vis-à-vis* preferred species), either through the creation of structure (e.g., *acadjas*, see below) or direct feeding of fish held in cages or enclosures. Dozens of new adopters of cage and pen technology piloted and disseminated by CP34 testify to its utility and relevance to local opportunities and constraints enabled through participatory research.

In Lake Nasser, the interdiction of both species introduction (to take advantage of the large ecological niche left unexploited in the plankton-rich pelagic zone) and the use of feeds, further limits the options for increasing water productivity. The elimination of predators by protecting stocked fish in enclosures has not yet shown any tangible result, but the processes through which

participatory trials were conducted has improved the working relationship between fishers and research.

All of these experiences underline the importance of good social, economic and biological baseline to underpin management decision-making and to the drawing of clear conclusions from field trials. The generally congenial atmosphere among stakeholders that evolved over the course of CP34 was crucial in the collection of quality data and successful project implementation and has laid the foundation for future gains. However data collection remains problematic in all of the basins studied and a constraint to complete modeling of the ecosystem and fishery.

From our research, it appears that the interventions which yield the highest returns on research and extension investment, as well as time and money contributed by local stakeholders tend to be out of reach of the poorest of the poor. Two reasons seem to predominate: 1) capital required for enclosure, cage or stock enhancement exceeds the spending power of the lower echelons of society and, 2) management skills and an orientation towards organized labor investment are generally lacking among the very poor.

Benefits accruing to the poor through the value chain of culture-based fisheries activities (e.g., employment opportunities, lower cost fish for home consumption) are possible, but were not documented in this study. For the poor to be directly involved at a level that has a chance of producing impacts on a scale with the levels of poverty prevailing in Egypt, Ghana and India will require substantial government and/or NGO involvement, which may take the form of subsidies in terms of capital and/or logistical and technical support. In the absence of such subsidies, development of the culture-based fisheries sub-sector will continue to be a haphazard affair with increased productivity resulting from the occasional happy coincidence of competent management combined with community support, sound technology and adequate capital.

Section 2: Socio-institutional analysis

2.1. General introduction to the section

Improving the productivity of water-bodies is clearly dependent on the capacities of local actors to solve technical innovation challenges. This has been fully illustrated through the three cases reviewed above (small-scale cage culture in Lake Volta, enclosure in Lake Nasser, cage and pens in India). Institutional economists and social scientists would however argue that adoption and dissemination of innovation are not simply the result of technical 'fix'. A great part of the factors which influence the success (and the failure) of the adoption and/or viability of technical innovations are related to social, economic and more broadly, institutional factors.

In order to reflect and account for this reality the second main component of the project was aimed at focusing on socio-institutional dynamics. Its specific objective was to analyze the overall human contexts of the reservoirs where the project was operating and to identify socio-institutional factors influencing reservoir fishery productivity.

2.2. Reservoir productivity and institutional arrangements in India

2.2.1. Introduction

Our initial analysis of the Indo-Gangetic Basin situation revealed that the productivity of the IGB reservoirs is in general below the national average, and well below some other countries performances. Further analyses were therefore performed in an attempt to 'explain' –or at least better understand- the various factors that affect reservoir productivity in the IGB. We did not however limit our investigations to bio-physical or ecological factors. Instead we hypothesized that the institutional context characterizing the communities (e.g. the type of leasing system adopted for the reservoir or its duration) greatly influences the decision-making process and the collective actions in relation to the reservoir fisheries operations (e.g. incentives or disincentive to invest, or to comply with existing regulation).

Objectives CPWF Project Report

We used for those investigations the database of 604 reservoir collected during the initial phase of the project. Only for a fraction of those reservoirs (82) however, a large enough combination of variables had been properly completed (see list in Table 2.1). We used this sub-sample of 82 reservoirs in the rest of the analysis presented below.

Table 2.1. Variables considered in the analysis

<i>Mean depth:</i>	Mean depth of the reservoir (meters)
<i>Area :</i>	Surface of the reservoir at Full Storage Level (ha)
<i>Fluct level :</i>	Index of water level fluctuation: difference between FSL and DSL ^(a) (ha)
<i>Yield :</i>	Total landing per year (kg) for the reservoir
<i>Productivity :</i>	Yield per ha [Yield / Area] (kg ha ⁻¹ year ⁻¹)
<i>Fishing days :</i>	Number of days per year fishing is operated on the reservoir (day year ⁻¹)
<i>Fishers :</i>	Number of fishers operating on the reservoir (man)
<i>Effort :</i>	Composite index of fishing effort [Fishers × Fishing days/Area] (man-day ha ⁻¹ year ⁻¹)
<i>Stock qty :</i>	Quantity of fingerlings released in the reservoir (individuals)
<i>CPUE :</i>	Catch per unit of effort [Yield / Effort] (kg man-day ⁻¹)
<i>Stock density :</i>	Stocking density [Stock qty Area ⁻¹] (fingerlings ha ⁻¹)
<i>Leasee :</i>	Group or individual who 'owns' the leasing [fishing cooperative: 1, group of fishers: 2, or private contractor: 3]
<i>Leasing:</i>	Method of lease [Open Auction 1, or other 2]
<i>Lease period :</i>	Period of the leasing (year)
<i>Fees :</i>	Leasing amount (Indian Rupees)
<i>Fees ha⁻¹ :</i>	Leasing per area [Fees / Area] (Rs ha ⁻¹)
<i>Rights :</i>	Group implementing the fishing [fishing cooperative: 1, local fishers: 2, or professional fishers: 3]
<i>Gear :</i>	Combination of fishing gear operated on the reservoir [1=G; 2=GC; 3=GCD; 4=GCDT; 5CD] ^(b)
<i>IMC :</i>	Proportion of Indian Major Carps in the landing (%)

Notes: (a): DSL: Dead Storage Level (b): G = gillnet; C = cast net; D = drag net; T = traps

2.2.2. Methods

Due to the nature of the variables and their general lack of normality (Table 2.2), conventional multivariable statistical analyses could not be applied. We used instead tests available from the software PRIMER (Clarke and Gorley, 2006) particularly adapted to those statistical constraints.

Table 2.2. Normality Test (Kolmogorov-Smirnov)

Variable	K-S distance	P-value	test	Variable	K-S distance	P-value	test
Log <i>depth</i> :	0.2673	P = <0.0001	Failed	Log <i>stock</i> :	0.1200	P = 0.1402	Passed
Log <i>area</i> :	0.1280	P = 0.0889	Passed	Log <i>dens</i> :	0.1669	P = 0.0057	Failed
Log <i>fluc level</i> :	0.1053	P = 0.2924	Passed	<i>Leasee</i> :	0.5361	P = <0.0001	Failed
Log <i>yield</i> :	0.1306	P = 0.0761	Passed	<i>Leasing</i> :	0.5377	P = <0.0001	Failed
Log <i>prod</i> :	0.1613	P = 0.0089	Failed	<i>Period</i> :	0.4372	P = <0.0001	Failed
Log <i>fish-day</i> :	0.1555	P = 0.0140	Failed	Log <i>fees</i> :	0.1359	P = 0.0547	Passed
Log <i>fishers</i> :	0.1094	P = 0.2428	Passed	Log <i>fees/ha</i> :	0.1222	P = 0.1242	Passed
Log <i>effort</i> :	0.1244	P = 0.1087	Passed	<i>Rights</i> :	0.4795	P = <0.0001	Failed
Log <i>CPUE</i> :	0.1114	P = 0.2203	Passed	<i>Gear</i> :	0.4693	P = <0.0001	Failed
				<i>IMC</i> :	0.3171	P = <0.0001	Failed

Overall the 'quality' of the data was relatively poor and high variances were observed in the data (even after log transformation and normalization), as illustrated by the Draftman plots of some of the main variables (Fig.2.1). Note that the first column displays the productivity scatter plots.

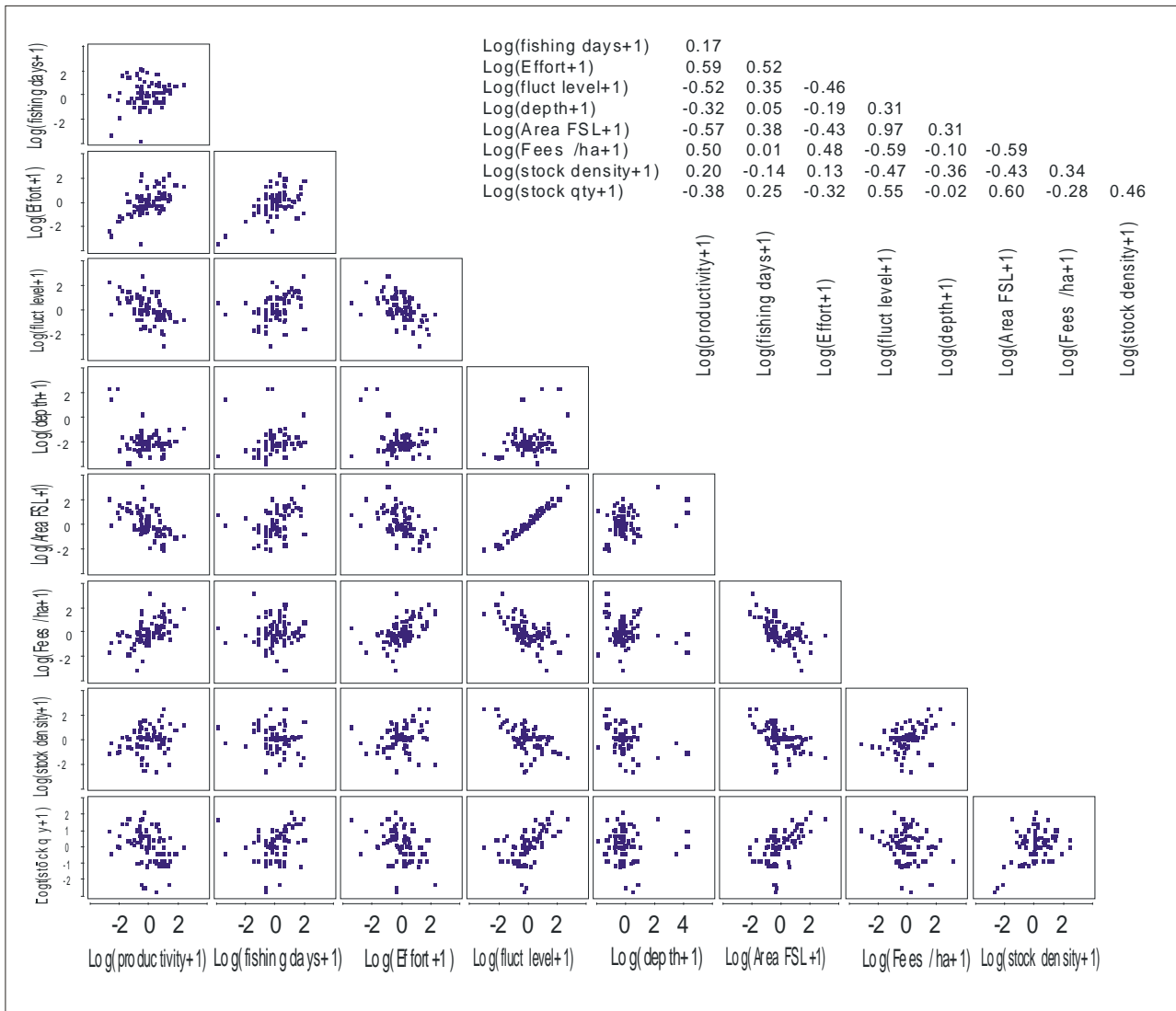


Fig.2.1. Draftman plots and correlation coefficients between variables

2.2.3. Results and analysis

Bio-physical model

We adopted a two-step analysis. First a 'bio-physical' model was considered where the productivity of the 82 reservoirs was tentatively correlated to a sub-set of physical and stocking-related variables. For this we used the BEST procedure (BVSTEP option) -after adequate transformation. The objective of BEST procedure is to search subsets of a multi-variable matrix (in our case a subset of physical and stocking-related variables) which best explain a given factor (reservoir productivity). The principle is to search for high rank correlations between a similarity matrix and a resemblance matrix generated from different variable subsets (see details in Clarke and Gorley, 2006).

Applying this procedure to our data, the analysis shows that the combination of explanatory variables which best explains the reservoir productivity includes 3 variables *effort*, *mean depth*, and *area*. The statistical significance of the model was confirmed by a global test (Table 2.3).

This result is conformed to the expectations. In particular the fact that the two variables *depth* and *area* have a significant effect on *productivity* is in line with the literature. On the other hand, the

Objectives CPWF Project Report

absence of correlation with any of the variables reflecting the stocking process (*stock density* or *stocking quantity*) is more surprising. A second point worth noticing is the positive correlation between *productivity* and *effort* (the variable for which the correlation is actually the strongest). This point will be discussed further below.

Table 2.3. Result of the BEST analysis for the bio-physical model

Explanatory variables	Dependent Variable		
a <i>gear</i>	<i>productivity</i> (Log)		
b Log(<i>effort</i> +1)			
c Log(<i>fluct level</i> +1)	Steps for global test:		
d Log(<i>depth</i> +1)	No.Vars	Corr.	Selections
e Log(<i>area</i> +1)	1	0.301	Log(<i>effort</i> +1)
f Log(<i>stock density</i> +1)	2	0.306	Log(<i>effort</i> +1), Log(<i>area</i> +1)
g Log(<i>stock qty</i> +1)	3	0.338	Log(<i>effort</i> +1), Log(<i>area</i> +1), Log(<i>depth</i> +1)

Global Test
Sample statistic (Rho): 0.338
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample)
Number of permuted statistics greater than or equal to Rho: 0

General model

Second, a general model was constructed using not only physical and stocking-related variables but also some of the socio-institutional variables for which data had been collected. Those included the period and price of the leasing arrangement, the identity of the lessee who obtain the temporary management rights (the lease) over the reservoir and the identity of those who are subcontracted by the lessee to fish the reservoir on his behalf. A BEST procedure was applied to those potential variables. It indicates that the variables that best explain the productivity are (in decreasing order): *lessee*, *fishing effort*, *reservoir area*, *lessee period*, and *mean depth* (Table 2.4). The statistical significance of the test was confirmed at a 0.1% level.

Table 2.4. Result of the BEST analysis for the general model

Explanatory variables	Dependent variable		
a Log(<i>effort</i> +1)	<i>productivity</i> (Log)		
b Log(<i>fluct level</i> +1)			
c Log(<i>depth</i> +1)	Steps for global test:		
d Log(<i>area</i> +1)	No.Vars	Corr.	Selections
e <i>Lessee</i>	1	0.303	<i>Lessee</i>
f <i>Lease period</i>	2	0.307	<i>Lessee</i> , Log(<i>effort</i> +1)
g <i>Rights</i>	3	0.319	<i>Lessee</i> , Log(<i>effort</i> +1), Log(<i>area</i> +1)
h Log(<i>stock density</i> +1)	4	0.349	<i>Lessee</i> , Log(<i>effort</i> +1), Log(<i>area</i> +1), <i>Lease period</i>
i Log(<i>stock qty</i> +1)	5	0.352	<i>Lessee</i> , Log(<i>effort</i> +1), Log(<i>area</i> +1), <i>Lease period</i> , Log(<i>depth</i> +1)

Global Test
Sample statistic (Rho): 0.352
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample)
Number of permuted statistics greater than or equal to Rho: 0

The comparison between Table 2.3 and Table 2.4 reveals some instructive results. First there is a strong coherency between the two models in the sense that the explanatory variables identified through the bio-physical model (*effort*, *mean depth*, and *area*) were identified again in the general

model (in the same order). However, two new socio-institutional variables were also identified through the BEST procedure: *leasee* and *lease period*. Logically the explanatory power of the 'general' model is stronger than the one of the bio-physical model –as the model contains more significant variables. But the important point is that the first variable of this general model is one socio-institutional variable, namely the category of the *leasee*. This result will be discussed in greater length below.

A Principal Component Analysis (PCA) was then conducted on the full set of explanatory variables in order to explore the potential 'structure' that links some of those variables together. The results are shown in Table 2.5. The first 3 axes of the PCA explain 83.7% of the variance of the explanatory variables and the first axis PC1 explains 47.7%.

Table 2.5 indicates that the first axis (PC1) is mainly explained by the following variables (in decreasing order): *leasee* category, *access rights*, *lease period*, and *mean depth* while the second axis (PC2) is explained by the *stock density* and the *area*. Fig.2.2 represents the first two axes of the PCA. On the figure, the different categories of leasee arrangements and access right subcontracts have been distinguished (using the codes defined in Table 2.1, i.e. fishing cooperative =1, group of fishers = 2, and private contractor = 3). Thus the [3-2] combination (shown as red lozenge in Fig.2.2) indicates reservoirs where the leasee is a private contractor [3] who contract a group of individual fishers [2] to fish the reservoir for him. This corresponds for instance to the situation of the Pahuj reservoir. In contrast the Dahod reservoir is under a [1-1] combination (blue square) as it has been leased by a cooperative, the members of which exploit it themselves. The figure shows that those arrangements have a strong influence on the other characteristics of the reservoirs. Note also the 'logical' result displayed along the second axis PC2, where *area* and *stock density* appear to be inversely related. This is expected as the variable *stock density* is by definition an inverse function of *area* –see Table 2.1 for definition.

Table 2.5. Principal Component Analysis

<i>Eigenvalues</i>			
PC	Eigenvalues	%Variation	Cum.%Variation
1	2.86	47.7	47.7
2	1.55	25.8	73.5
3	0.612	10.2	83.7

<i>Eigenvectors</i>			
(Coefficients in the linear combinations of variables making up PCs)			
Variable	PC1	PC2	PC3
Log(<i>depth</i> +1)	-0.437	0.215	-0.485
Log(<i>area</i> +1)	-0.209	0.590	0.712
<i>Leasees</i>	0.540	0.052	-0.115
<i>Lease period</i>	-0.462	-0.254	0.227
<i>Rights</i>	0.476	0.391	0.050
Log(<i>stock density</i> +1)	0.184	-0.621	0.437

Table 2.6. OLS model between productivity and the variables' coordinates along PC1

Linear Regression model					
Dependent variable: log(<i>prod</i>)		explanatory variable: PC1			
R = 0.726	R ² = 0.528	Adj R ² = 0.521			
Coefficient	Std. Error	F	P		
Constant	0.3016	0.01515	19.92	<0.0001	
PC1	0.0832	0.00892	9.33	<0.0001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	1.60	1.5979	87.1	<0.0001
Residual	78	1.43	0.0183		
Total	79	3.03	0.0383		
Normality Test:		Passed (P = 0.0948)			
Homoscedasticity Test:		Passed (P = 0.3609)			

Exploring further the data reveals a decreasing gradient of productivity from right to left along PC1 –as illustrated by the 'bubbles' analysis in Fig.2.3. The reservoirs located on the right side are on average characterized by higher productivity than those located on the left-hand side. This result was confirmed through OLS estimation between *productivity* (log-transformed) and the coordinates of the variables along the axis PC1 (Table 2.6).

From these different analyses, it appears clearly that the different types of institutional arrangements -in particular the types of leasing contracts and the associated subcontracts on access rights- are critical in shaping the overall 'landscape' of cultured-based fisheries activities in the IGB. Based on Fig.2.1, a series of hypotheses was proposed:

- Hypothesis No.1: arrangement 1-1 is characterized by lower productivity than the other arrangements

Objectives CPWF Project Report

- Hypothesis No.2: arrangement 3-2 is characterized by higher stock density than the other arrangements (or alternatively, arrangement 1-1 is not characterized by a stock density different from 3-3 and 2-3)

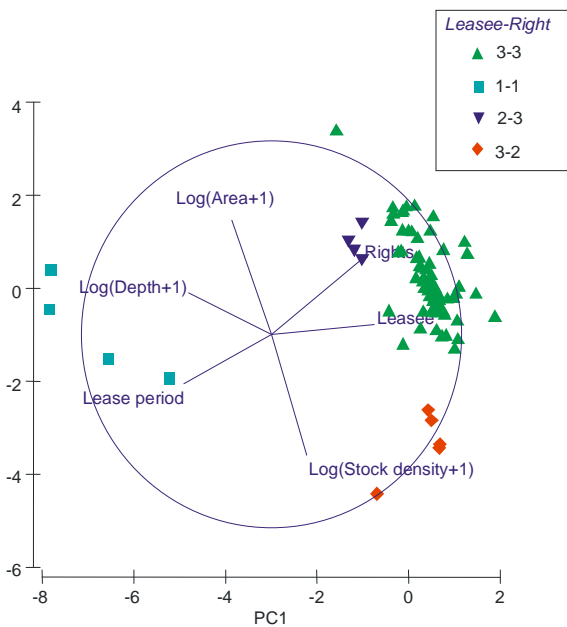


Fig.2.2. The two first axes of the Principal Component Analysis conducted on the explanatory variables

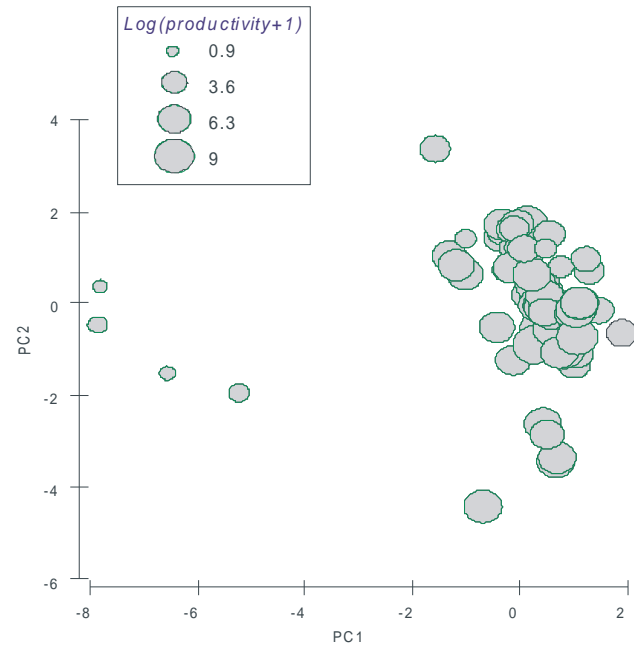


Fig.2.3. The size of the bubbles, proportional to the productivity, suggest a decreasing gradient along axis 1.

We investigated these two hypotheses through a series of tests. First a SIMPER procedure was applied in order to estimate the contribution of each variable to the distances between the four institutional arrangements. The principle of a SIMPER analysis is to decompose dissimilarities matrixes into percentage contributions between all pairs of variables (Clarke and Gorley, 2006). When applied to our data (Table 2.7) the SIMPER analysis shows that the arrangements 3-3 and 2-3 are very 'close' to each other (average squared distance = 12.58), confirming the graphical observation of Fig.2.2.

Perhaps more importantly, the SIMPER analysis reveals that although productivity is one of the factors which differentiates arrangement 1-1 from the others arrangements (confirming at first sight hypothesis No.1 above), the main differentiating factor is depth, not productivity. In one case (2-3 vs 1-1) productivity is actually not amongst the 2 most significant differentiating factors. Incidentally this result was also shown in the PCA where depth appeared to be the main 'bio-physical' factor explaining PC1. In other terms, the low productivity characterizing the arrangement 1-1 is mainly explained by the mean depth of the reservoirs (deeper than those operated under the other arrangements), and not by the lack of efficiency or investment (in particular in terms of stock density).

The second result of interest is that stock density is amongst the 2 main factors differentiating the arrangement 3-2 from 2-3 and 3-3, thus confirming hypothesis No.2 above. In contrary arrangement 1-1 is not different from arrangements 3-3 or 2-3 in terms of stock density (Table 2.7). Those results were confirmed statistically through a series of Kruskal-Wallis (K-W) analyses on ranks.

First a K-W on ranks ($H = 21.4$, d.f. = 3, $P = <0.0001$) completed by a Pairwise Multiple Comparison Procedures (Table 2.8) confirms that 1-1 is statistically operating on deeper reservoirs than the other arrangements. The KW analysis also reveals that the groups of reservoirs operated

under 3-2 is characterized by a mean depth which is statistically shallower than the reservoirs under 2-3 and 3-3 arrangements. In sum, reservoirs under the arrangement 3-2 turn to be small, shallow water-bodies (Table 2.9).

A parallel KW shows that reservoirs under 3-2 are also characterized by higher stock density than the other arrangements ($H = 24$, d.f. = 3, $P = 0.0001$) but also that 1-1 has not a statistically lower stock density than 3-3 (Tables 2.8 and 2.9).

Table 2.7. SIMPER analysis with a cut-off threshold set at 40%

Groups 3-3 & 2-3 Average squared distance = 12.58				
Variable	Av.Sq.Distance	Sq.Distance/SD	Contrib%	Cum.%
Log(<i>area</i> +1)	2.44	1.25	19.41	19.41
Log(<i>stock qty</i> +1)	2.3	0.72	18.26	37.67
Log(<i>productivity</i> +1)	1.97	0.71	15.67	53.34

Groups 3-3 & 1-1 Average squared distance = 36.64				
Variable	Av.Sq.Distance	Sq.Distance/SD	Contrib%	Cum.%
Log(<i>depth</i> +1)	12.9	1.52	35.21	35.21
Log(<i>productivity</i> +1)	6.62	1.41	18.06	53.27

Groups 2-3 & 1-1 Average squared distance = 34.45				
Variable	Av.Sq.Distance	Sq.Distance/SD	Contrib%	Cum.%
Log(<i>depth</i> +1)	12.6	1.53	36.44	36.44
Log(<i>fishing days</i> +1)	7.79	1	22.62	59.06

Groups 3-3 & 3-2 Average squared distance = 22.65				
Variable	Av.Sq.Distance	Sq.Distance/SD	Contrib%	Cum.%
Log(<i>fee/ha</i> +1)	5.45	1.01	24.06	24.06
Log(<i>stock density</i> +1)	4.7	0.95	20.76	44.82

Groups 2-3 & 3-2 Average squared distance = 31.31				
Variable	Av.Sq.Distance	Sq.Distance/SD	Contrib%	Cum.%
Log(<i>area</i> +1)	10.4	4.58	33.17	33.17
Log(<i>stock density</i> +1)	5.14	1.57	16.42	49.6

Groups 1-1 & 3-2 Average squared distance = 66.27				
Variable	Av.Sq.Distance	Sq.Distance/SD	Contrib%	Cum.%
Log(<i>depth</i> +1)	20.4	1.65	30.77	30.77
Log(<i>productivity</i> +1)	9.95	3.5	15.01	45.78

Table 2.8. Pairwise Multiple Comparison Procedures (Dunn's Method) for both depth and stock density

Comparison	Diff of Ranks	depth			Comparison	Diff of Ranks	stock density		
		<i>p</i>	Q	<i>P</i> <0.05			<i>p</i>	Q	<i>P</i> <0.05
1-1 vs 3-2	104.6	4	4.512	yes	3-2 vs 1-1	115.7	4	4.46	yes
1-1 vs 2-3	49.17	3	2.788	yes	3-2 vs 3-3	73	3	3.51	yes
1-1 vs 3-3	39.34	2	2.547	no	3-2 vs 2-3	55.2	2	2.53	no
3-3 vs 3-2	65.26	3	3.603	yes	2-3 vs 1-1	60.5	3	3.39	yes
3-3 vs 2-3	9.83	2	0.975	no	2-3 vs 3-3	17.8	2	2.00	no
2-3 vs 3-2	55.43	2	2.769	yes	3-3- vs 1-1	42.7	2	2.56	no

Table 2.9. Statistic summary of the reservoirs grouped by arrangements

	Arrangement	N	Mean	Std Dev	95%CI
Depth (m)	1-1	7	78.36	74.417	55.13
	2-3	18	4.54	1.906	0.88
	3-2	5	1.56	0.166	0.15
	3-3	107	5.45	3.866	0.73
Area (ha)	1-1	7	6539	9785	7249
	2-3	18	778	596	275
	3-2	5	6	2	2
	3-3	107	680	1976	374
stock density (fingerlings ha ⁻¹)	1-1	8	557	267	185
	2-3	34	3906	4879	1640
	3-2	5	25402	1926	16884
	3-3	110	2938	5257	983
stock qty (fingerlings)	1-1	8	297375	250974	173913
	2-3	34	610940	789462	265363
	3-2	5	160000	147479	129268
	3-3	110	873268	1372244	256438

Further analysis shows that the higher density of stocking under 3-2 is more the consequence of the small size of the water bodies (in so far as the quantity stocked under this arrangement is actually lower than under all the other arrangements (including 1-1) –see Table 2.9. A complementary KW on ranks indicates that indeed there is no statistically difference between the four arrangements in terms of quantity stocked ($H = 3.89$, d.f. = 3, $P = 0.27$).

2.2.4. Discussion

In the literature, factors constraining tropical reservoir productivity are usually related to morphometric (area, depth, shoreline), edaphic (nutrients loading) and/or climatic (e.g. flushing rate, water level fluctuation) conditions. A rich body of literature is available that proposes to link existing reservoir productivity to a wide range of environmental factors.

Very little has been proposed on the other hand to include socio-institutional considerations into those discussions, despite the significant literature that emphasizes the importance of collective actions and social and/or economic factors in explaining activities related to the exploitation of natural resources and common pool resources (e.g. Ostrom 1990).

The research presented above was a first attempt to address this flaw. Using the IGB data-base created in the early stages of the project, we explored some new directions regarding the potential factors influencing the productivity of the IGB reservoirs. The investigations were obviously limited by the nature and quality of the information, but interesting conclusions were nevertheless achieved. Some of those results, not only confirm the crucial role that socio-institutional factors seems to play in shaping the system productivity –something one should not be surprised to observe-, but also suggest –perhaps more unexpectedly- that arrangements supporting private ownership may not necessarily lead to better or more efficient outcomes when compared to collective arrangements.

Let us first recall that our results are in line with the more conventional work focusing on the role of bio-physical factors. Our first model confirms in particular that the productivity of the IGB reservoirs is influence by the size and depth of the reservoirs, two of the factors that are usually recognized to have a strong influence on reservoir productivity. The absence of correlation with any of the variables reflecting the stocking process (*stock density* or *stocking quantity*) is more disappointing. This suggests a poor efficiency in the mastering of the stocking techniques for the group of reservoirs included in the data-base.

Secondly, the positive correlation between *productivity* and *effort* is worth noticing but more complex to account for. As '*effort*' is a variable resulting from the number of fishers operating in the reservoir considered combined with the number of fishing days per year (see Table 2.1), one potential explanation is that this effort variable is actually driven by productivity. The higher the 'natural' productivity of the reservoir, the larger the number of fishers which the reservoir can sustain.

In a second part of the analysis, we investigated the potential role of what we termed socio-institutional factors. Those included the period and price of the leasing arrangement, the identity of the leasee who obtained the temporary management rights (the lease) over the reservoir and the identity of the fishers who were subcontracted by the leasee to fish the reservoir on his behalf.

In the literature, the absence of individual property right and market mechanisms in the production, distribution and consumption of public goods is usually thought to render these goods susceptible to under-supply and over-consumption (Sargeson, 2002). In particular neoclassical economists argue that private ownership provides the necessary incentive for actors to invest and develop their activity. Johnson (1972) for instance explains that, for a rational individual to be able to maximize his rewards and minimize his costs for exploiting a resource, costs and rewards should be internalized. According to his theory, private individual property only allows this and provides incentives to ensure that marginal benefits are being maximized. In our case this view means that leasing arrangements under a private contractor are expected to be characterized by higher investment (e.g. in terms of stocking density), better management and therefore higher outputs (productivity).

Alternative approaches however have been developed which challenge the neoclassical theory. A few authors in this arena deny the validity of the basic collective action and CPR management problems outlined by the neoclassical writers. Rather, they suggest that other behavioral considerations condition and work within the individual benefit versus collective good decision structure and suggest mechanisms through which these considerations exert communication and facilitate the learning and convergence of interests that make cooperation more likely (Morrow 1994, Seabright 1993, Runge 1984). They argue that in the CPR context of mutual resource reliance, the dominant individual incentive is neither free-riding nor refusal to cooperate, but rather coordination (Runge 1984, 1992).

Despite these arguments in favor of local collective management, there is still a strong belief, specially among western society, that such collective arrangements are inherently unstable, subject to inevitable pressure from free riders and are bound to be degraded into 'tragedy of commons' situation. In our case this means that arrangement 1-1 corresponding to a situation where both investment and management related to the reservoir stocking and fishing are made by a cooperative are expected to be less effective than other arrangements involving private contractors.

Our results challenge those assumptions. While arrangements 1-1 appear indeed to be characterized by lower productivity than the other arrangements, the analysis shows that this lower productivity is mainly related to the mean depth of the reservoirs, which in those cases is statistically larger than for the other reservoirs managed under other types of contract. In order terms, the low productivity characterizing the arrangement 1-1 is not due to a lack of efficiency or investment (in particular in terms of stock quantity) but to some bio-physical characteristics of the reservoirs.

The second result that challenged the conventional wisdom is the fact that although the arrangements 3-2 appears to be characterized by higher stock density than the others –and in particular than the 1-1 arrangement-, a feature than some would quickly interpret as the evidence of the superiority of the private ownership over collective one in terms of investment, the data reveal that this higher density under 3-2 result instead from the fact that the reservoirs operated under 3-2 (but also 3-3 and 2-3) are particularly small. When one analyzes the stock quantity – which reflects more appropriately the actual level of investment- one observes that the arrangement 3-2 is actually characterized by a lower stock quantity than all the other

arrangements -and in particular the arrangements 1-1. In other words, the view that cooperatives are likely to invest less than private contractors is not confirmed by our data.

What those different results show is that private entrepreneurs target specifically small, shallow reservoirs as they know that those are naturally particularly productive, while they deliberately disregard larger, deeper reservoirs. In those conditions, these larger reservoirs are more likely to remain under the management of cooperatives, which is what we observed here. On the other hand, these cooperatives can not compete with the private contractors for smaller (but more productive) reservoirs.

In sum what is often interpreted as a better capacity of private contractors to invest and manage reservoirs is in fact the result of their higher financial capacity to win the leasing bids of the small-shallow reservoirs. The cooperatives and the independent groups of fishers, characterized by less cash facility are then left with the remaining larger (and less productive) reservoirs.

2.3. Institutions of Lake Nasser fishery and their impact on the reservoir productivity

2.3.1. Introduction

As the analysis of the Indo-Gangetic basin presented above has clearly demonstrated, the capacity of tropical reservoirs to produce fish does not depend only on their bio-physical characteristics. A significant part of the productivity of these systems is influenced by the human (social, economic, institutional) dynamics of the activities which take place around the reservoirs. Lake Nasser is no exception to this rule. In this section we present the results of two distinct –but closely related– analyses that were implemented as part of CP34 in an attempt to better understand the human context of the Lake Nasser fishery and analyze how some of the socio-institutional factors that characterize the fishery may become obstacle to, or conversely help, the productivity of the system.

The first of those two studies looked retrospectively at the policy and management reforms that have been implemented in the fishery since the 1970s. The analysis showed how those various economic and management measures which were initially aimed at responding to a perceived environmental crisis where the resource was seen as over-exploited, eventually had a totally opposite and counterproductive result. They encouraged an increasing number of fishers to engage in a parallel black market whereby a substantial part of the production started to be smuggled away from the 'centralized' commercialisation channels, thus reducing further the control that the central authority was trying to re-establish on the fishery.

The second analysis was a micro-economic analysis that looked at the various contractual arrangements existing in the Lake Nasser fishery between different actors (license owners, boats owners, fishers). Like in many fisheries in the world, the remuneration of nearly all of the 8000 fishers operating in the Lake Nasser fishery is mainly determined by share contracts. One remarkable characteristics of this situation, however, is that no less than four different types of share arrangements co-exist at the present time in the fishery. The objective of the analysis was to determine whether those different contracts influence the behavior of the different economic actors and eventually the productivity of the fishery.

2.3.2. Impacts of macro-economic reforms on the fishery productivity

The context

The recorded yields of the Lake Nasser fishery have varied considerably since the creation of the lake in 1963 (Fig.2.4). In the first two years following the filling up of the lake, the production reached 1000 tonnes caught by a few hundred fishers. From then on, the development of the fishery accelerated.

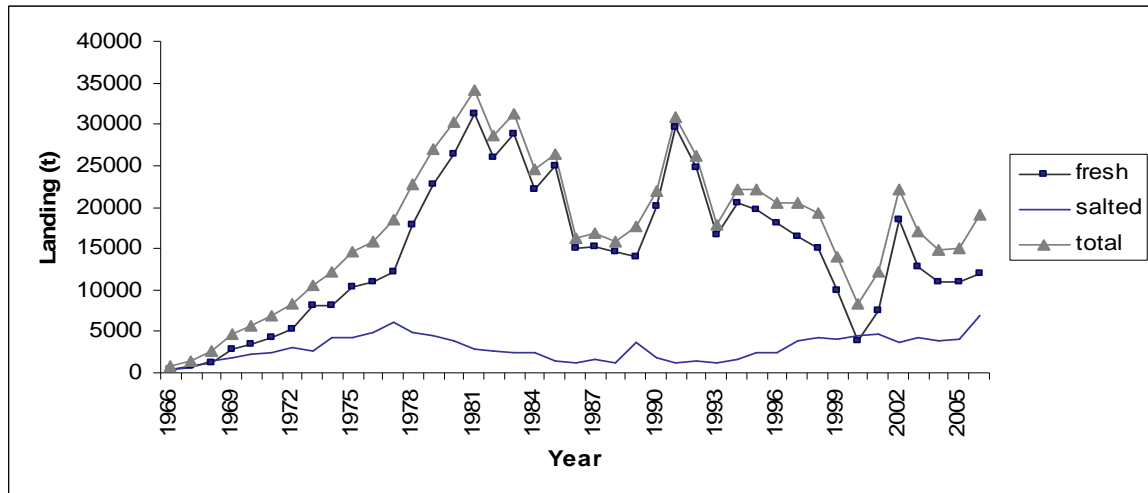


Fig.2.4. Evolution of the landings for fresh, salted and total landing from Lake Nasser's fishery. source: LNDA (unpublished) landing data.

In the early 1970s, the growing potential of the fishery rapidly attracted an increasing number of migrants from all parts of Egypt. Along with the development of the fishery and its economic potential, interest for this new income opportunity also steadily increased amongst the local populations. In order to reduce the potential conflicts that the entry of these new actors might have created, a license system was introduced in the fishery. Without license, fishers were not allowed to operate on the lake. Initially, licenses could be sold and/or exchanged. Some boat owners thus managed to acquire as many as 100 licenses.

During the first years of the Lake Nasser fishery development, a single state-owned company organized the marketing of the fish in Aswan. This company, the Egyptian Company for Fish Marketing (hereafter called Taswik), was linked administratively to the Ministry of Supply. At that time, the fishery, as well as the fisherfolk, was of little concern to the central government whose main interest was to provide the country with cheap protein. The price of fish from Lake Nasser was, therefore, fixed at a very low level and the whole commercialisation process was under state control¹⁰.

Over the two decades following the landing peak of 1981 where more than 34,000 tonnes were caught, the fishery yield diminished continuously. It passed from 650 kg boat⁻¹ day⁻¹ in 1981 to a mere 35 kg boat⁻¹ day⁻¹ in 2000. This declining trend was interpreted by many scientists as the sign of serious ecological over-exploitation of the resource (e.g. Khalifa et al., 2000; MALR-LNDA, 2001) despite the fact that the number of fishers had not necessarily increased over that specific period. Faced with those decreasing landings, the management agencies imposed a series of new measures. A closed period and a minimal legal size on the catch were introduced in an attempt to release the pressure over the resource.

Smuggling, issue No.1 in Lake Nasser

While the price of fish in the rest of Egypt was already free in the 1980s, the government continued to maintain a fixed price for Lake Nasser landings. This exception was officially justified by the recent history of the lake: whereas other lakes and coastlines in Egypt had been supporting long-established fishing communities, Lake Nasser was not hosting any permanent fishing population but only seasonal fishers. It was argued that this particular situation was a good reason for the central authority to control the fishery, with no other (social) consideration than maximizing the supply of cheap fish to the rest of the increasing urban population of Egypt.

¹⁰ This fixed price system did not, however, include salted fish, the price of which had been set free since the beginning of the fishery.

Albeit having increased over time, passing, for instance, from EGP 0.64 to EGP 1.05 per kg between 1988 and 1990, the fixed price was still more than 25% below the free national market at that time. This situation gave both fishers and traders a very good incentive to engage in a parallel black market whereby an increasing quantity of fish is diverted from the official channels. Secretly landed in isolated creeks at night, these fish are loaded on trucks and sold directly on the urban markets of Cairo and other main towns of the country. Smuggling fish traders could offer a better price (than the fixed price) to the fishers and still make a profit as the difference between the price at the Lake's harbors and at the national market was substantial.

In addition to a higher price, smuggling also offered fishers the opportunity to avoid some of the constraining governmental regulations. For instance, the government levied taxes on the official market to finance the development of the fishery, the management of the harbors and the social security system for the workers. These taxes may not be prohibitive but still contributed to making smuggling more profitable than official business. More importantly, smuggling offers the possibility to circumvent the stringent resource conservation regulations put in place by the government (the minimum size regulation and the seasonal closure).

Another major factor that has contributed to the magnitude of the smuggling is that the Lake Nasser fishery - like a large number of artisanal fisheries in the developing world - has been attracting an increasing number of poor people from all over the country. In Egypt, where Nasser's land reform has been progressively dismantled by several series of counter-reforms, it is estimated that about 75% of the small tenants have been forced to leave the agricultural sector in the last 10 years (Bush, 2002). In those conditions, the Lake Nasser fishery played a substantial role as 'labour buffer' (Jul-Larsen et al., 2003) for many poor or landless *fellahin* who turned to the fishery as a safety net activity. The problem is that the total number of license has been fixed to 3000 by the authority and license can not be sold or bought. As a result, many fishers are now operating illegally in the fishery (without a license) and can not, therefore, land their catch at the official landing sites. For them the only solution is to go through the black market. In 2006, the number of unlicensed fishers was estimated to be about 3000 (Habib, 2006 pers. comm.).

Finally, the form of ownership of the fishing rights and the nature of the labor arrangements also encouraged registered fishers to smuggle. In particular, the laborers who all operate under a sharecropping system, have good reasons to engage in smuggling. For them, even a price much below the free market level often left them better-off than with the meager revenues that they obtain through the sharecropping system.

In summary, our analysis shows that many actors are facing various, sometimes additive or complementary, reasons to support and participate in the black market. In fact, the fact that smuggling benefits actors on both sides of the trade equation (fishers and fish traders) makes the whole cycle even less likely to be broken. In this regard, the statistics are impressive. In 2006 alone, the police and the LNDA arrested as many as 357 trucks filled with smuggled fish, that is, more than one truck a day if we account for the fishery closed season. This statistic gives an idea of the intensity of the smuggling and of the large economic and institutional forces that create it. In effect, fish smuggling does not involve only poor fishers but also a substantial number of better-off fish traders. It is a 'big business' and many actors in the sector would agree that it has become almost a formal activity. Today it is estimated that probably half the total landings of the Lake Nasser fishery is smuggled.

2.3.3. Impact of share contract on Lake Nasser fishery's productivity

Far from comprising a homogenous and coherent social group, the majority of the fisherfolk involved in the activity of Lake Nasser fishery are seasonal, unsettled, workers coming from different parts of the country. Those fishers operate from temporary fishing camps established along the 7800 km of the lake's shorelines. With no electricity, no running water and no access to public services, the living conditions in those remote camps are rough. Only male fishers live there, usually staying in rudimentary cane-made shelters for up to seven months.

The remuneration of nearly all of those fishers is partially determined by share contracts, though the method of calculation and size of the share varies by contract type (see below). Four main categories of share contracts can be identified. Three apply to the 'raeis' (plural = *roasa*), who is the 'patron' or supervisor of the fishing camps. Those contracts –which we propose to call 'owners', 'renters', and 'partners' contracts- differ from each other by the contractual arrangements through which the *roasa* access licenses, and to a lesser extent their ownership of boats and gear. Fishers in the fourth category, called 'laborers', work for one *raeis*, living in his camp, and using his boats, gear, and licenses. In addition to those different groups engaged in fishing, a large number of license owners are non-fishing (urban-based) elite who act as "license lords", leasing their licenses out to *roasa*, in exchange for either fixed cash rent or a share of the catch. The features distinguishing the four contracts are sketched in Fig.2.5 and described below.

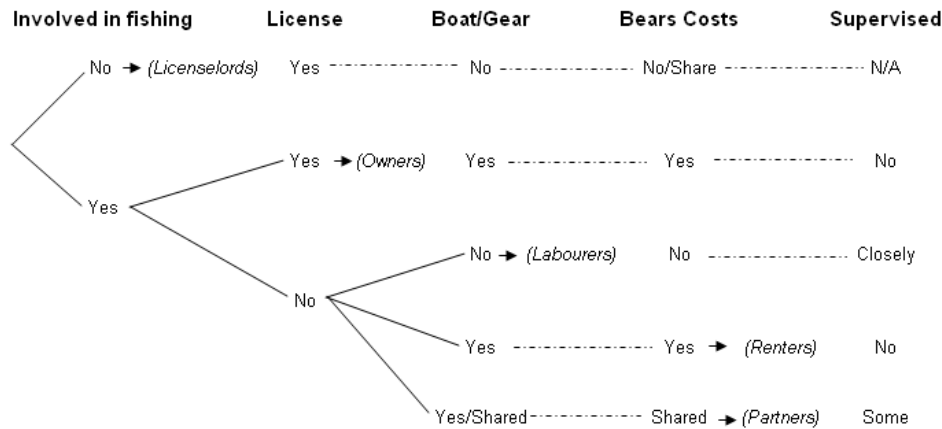


Fig.2.5. The four different contracts and their characteristics

Owners

Owner is the most straightforward category of *raeis'* contracts. Those owners own licenses (thus don't need to lease it from the license lords). They also own boats and gear, and bear all fishing operating costs except for the portion that they share with the crew through the payment of net shares. While they fish (unlike the license lords), they usually do not possess labor in the quantities necessary to operate all the boats of their own fleet, and must therefore hire laborers in order to be able to put their equipment and license to productive use. The owner category is also the most homogenous of the patrons, exhibiting the least intra-category variation in fleet size, investment, and production (see Table 2.10)¹¹.

Table 2.10. Socio-economic statistics of the fishers operating in Lake Nasser

	Owners	Renters	Laborers	Partners	Total
Household size	10.2	6.7	7.9	9.4	9.2
Age	45	33	38	42	41
Years fishing	27	15	20	24	23
Educated	44%	60%	15%	40%	41%
Has migrated	98%	90%	100%	88%	95%
Member of co-op	64%	30%	15%	28%	42%
Average number of licenses	4.1	6.5	1	7.7	4.8
Annual catch per boat (t)	4790	3872	6177	4133	4716
Owens boat(s)	98%	70%	0%	80%	72%
Owens gear	98%	80%	0%	86%	75%

¹¹ The statistics and contract analysis presented here are derived from a socio-economic survey that was carried out between January and May 2007 as part of CP34 activities -see Finegold et al (submitted) for a more comprehensive analysis. One hundred and twenty five fishers were interviewed during this survey. The nature of the data collected included basic personal information regarding family size, migratory status, age, and fishing history; employment details, including number of licenses, revenue sharing arrangements, affiliations to cooperatives, and engagement in other economic activities; and details of fishing activity, including production data, estimated operating costs, and information on boat and gear ownership.

Renters

Renters are professional fishers who typically own boats and gear, but do not own licenses. Like owners, they need to hire laborers, but they also need to lease a license, and in some cases to access money for capital investments. They are totally independent from the license lord except for rent payments. As rent is paid as a fixed amount, the license lord does not share operating costs either, though in some cases renters and license lord may jointly purchase boats or gear. The data indicate that renters tend to be younger and more educated than other fishers¹². They are also characterized by smaller household size than the other groups (Table 2.10).

Partners

Like renters, partners are professional fishers who do not own licenses. They often own boats and gear. The majority of partners provides some or all of the necessary fishing equipment and share both costs and revenues with the license lord, though a sub-part of them ('non cost-sharing' partners) bear all the costs and share only revenues with the license lord –see below.

All the other ('cost-sharing') partners own boats and gear, although it is not uncommon for them to share ownership of one or both with the license lord, or for the license lord to provide one or the other. Cost-sharing partners must hire laborers, lease a license, and access money for operating costs and in some cases capital investment. They share operational costs 'upward' with the license lord through the payment of license rent as a share of net income rather than gross, and 'downward' with laborers.

'Non cost-sharing' partners on the other hand do not share costs 'upward' with license lords, but only 'downward' with the laborers. Their license rent r is calculated as a share of gross income (between 10 and 35%).

Laborers

The last group is the 'laborers'. Laborers do not own boats or gear, and do not own or lease licenses. They possess only their own labor, and must work for a *raeis* who provides them with equipment and (access to) licenses in order to fish. They are recruited by those *roasa*, and work for them as crew members. They are paid their share at the end of the fishing season, and are provided with food and drink while in the fishing camp, the cost of which is subtracted from gross income along with other costs before shares are calculated.

Those different groups are obviously not similar as indicated by the various indicators shown in Table 2.10. What is however relatively surprising is that there is little difference in production per boat (annual catch per boat) between *roasa* who are share-workers (partners) and *roasa* who are not (owners and renters). On the other hand, laborers appear to catch more fish per boat than *roasa* do. The small share size laborers receive could constitute an incentive for higher production, as it requires them to work hard to earn even a small wage, paralleling the use of plot size to control effort in agriculture (Johnson 1950, Cheung 1969, Bhaduri 1983, Braverman and Srinivasan 1981). Indeed, laborers both carry out more fishing operations per week (Fig.2.6) and catch more than any other category (Fig.2.7).

While this incentives for higher production is in theory true of all of the fishers whose income is calculated on a share basis (i.e. the *roasa* as well), the small share size received by the laborers means that extra income obtained through extra effort could be critical to maintaining a subsistence level of income. The ratio of their marginal utility of income to marginal disutility of effort is substantially higher than that of the *roasa*, whose income is well above the subsistence level. A series of statistical test were then performed to explore further those points.

¹² Given that the average age the fishers surveyed began fishing is the same for all categories (17-18), it is possible that rental contracts may be gradually replacing partner contracts among the "new generation" of non license-owning patrons, though it is not clear whether this is their choice or imposed by licenselords

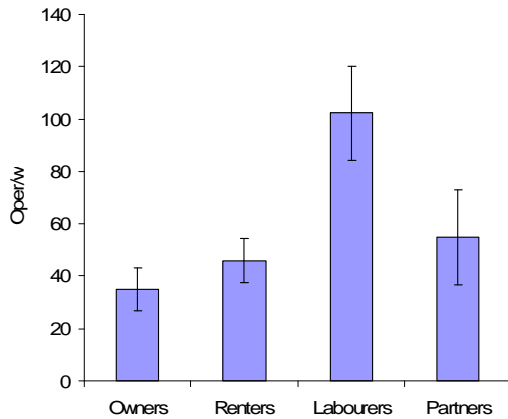


Fig 2.6. Number of fishing operation per fisher per week

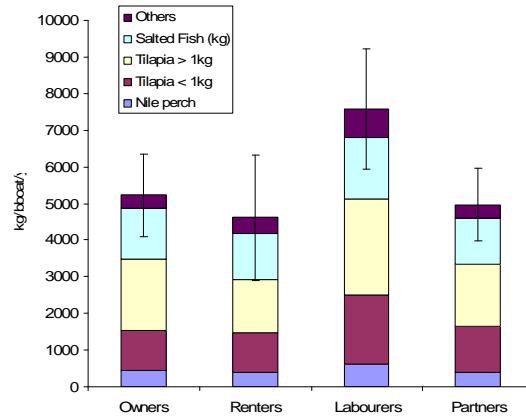


Fig 2.7. Catch per boat per year (in kg)

Statistical analysis

The objective of this statistical analysis was to test formally whether the productivity of the different groups of fishers is influenced by the nature of their contract. If, indeed, the form of the contract affects (positively or negatively) the productivity of the different groups through their contract, one would then expect to see statistical correlation between contract and productivity.

To test for this, we considered the Cobb-Dougllass production function of the fishery (measured in kg fisher⁻¹ year⁻¹) with inputs including fisher status (education, experience, cooperative membership), fishing effort (number of operation week⁻¹), fishing strategy (number of fishing day week⁻¹, diversity of gear, and dummy variable for geographic sector and targeted species), and a series of shift dummy variables: Owner, Partner, Renter, and Laborer defined as follows:

- Owner = 1 when the fisher is an owner; = 0 otherwise;
- Partner = 1 when the fisher is a partner; = 0 otherwise;
- Renter = 1 when the fisher is a renter; = 0 otherwise;
- Laborer = 1 when fisher is a laborer; = 0 otherwise.

As fishing effort was suspected to be endogenous, we used two-stage-least square (2SLS) procedures where the endogenous variable was instrumentalized by the number of licenses and the number of units in the four fishing gear categories: duk, kobok, sacarota, and Sinnar.

Table 2.11 summarizes the results of the tests. Durbin-Wu-Hausman χ^2 tests confirm that fishing effort is endogenous in the four models. The instruments in the first stage regression show relatively good levels of fit (Cragg-Donald Wald χ^2 test) and are uncorrelated to the error terms (Sargan test). F and AdjR² tests confirm the validity of the 2SLS models and Breusch-Pagan tests indicate the absence of heteroscedasticity in the error terms for those 2SLS regressions.

Table 2.11. 2SLS estimates. Model1 = owner; model2 = partner; model3 = renter; model4 = laborer

		Dependent variable = log(Productivity)			
Independent variables	Transformation	model 1	model 2	model 3	model 4
Operation / boat	number	-0.046 (< 0.001)	-0.047 (< 0.001)	-0.045 (< 0.001)	-0.046 (< 0.001)
Operation / boat ²	\wedge^2	0.001 (< 0.001)	0.001 (< 0.001)	0.001 (< 0.001)	0.001 (< 0.001)
Experience (year)	number	0.003	0.003	0.003	0.003

Objectives CPWF Project Report

		(0.715)	(0.720)	(0.710)	(0.735)
Education (year)	1 = literate	-0.086	-0.090	-0.093	-0.078
		(0.635)	(0.627)	(0.616)	(0.676)
Geographic sector	1-6	-0.030	-0.034	-0.035	-0.025
		(0.566)	(0.522)	(0.519)	(0.640)
Cooperative member	1 = yes	0.322	0.300	0.309	0.322
		(0.066)	(0.083)	(0.066)	(0.058)
Fishing days / week	number	0.327	0.330	0.330	0.330
		(< 0.001)	(< 0.001)	(< 0.001)	(< 0.001)
Gear diversity	number	0.338	0.333	0.339	0.336
		(0.029)	(0.029)	(0.028)	(0.027)
Nile perch	1 = yes	-0.242	-0.237	-0.238	-0.252
		(0.369)	(0.377)	(0.372)	(0.349)
Salted	1 = yes	-0.131	-0.132	-0.132	-0.12
		(0.522)	(0.521)	(0.519)	(0.564)
Other fish	1 = yes	-0.130	-0.120	-0.126	-0.132
		(0.563)	(0.584)	(0.571)	(0.549)
Owner	1 = yes	-0.038			
		(0.840)			
Partner	1 = yes		-0.051		
			(0.761)		
Renter	1 = yes			0.048	
				(0.828)	
Labourer	1 = yes				0.120
					(0.631)
Intercept		7.810	7.830	7.760	7.780
		(< 0.001)	(< 0.001)	(< 0.001)	(< 0.001)
Statistics summary					
N		110	110	110	110
R^2		0.481	0.478	0.485	0.480
Adj R^2		0.417	0.414	0.421	0.416
Root MSE		0.736	0.738	0.733	0.737
$F(k, N-k-1)$		9.190	9.150	9.210	9.210
Prob > F		< 0.001	< 0.001	< 0.001	< 0.001
Endogeneity tests H_0 : Regressor is exogenous					
Durbin-Wu-Hausman χ^2 test		13.689	13.952	13.137	14.195
(P -value)		(< 0.001)	(< 0.001)	(< 0.001)	(< 0.001)
Overidentification tests H_0 : Excluded regressors are uncorrelated to errors					
Sargan χ^2 test		6.537	6.726	7.084	6.327
(P -value)		(0.257)	(0.242)	(0.215)	(0.276)
First-stage regression estimators significance H_0 : Regressors are underidentified					
Cragg-Donald Wald χ^2 test		119.89	118.88	126.23	121.35
(P -value)		(< 0.001)	(< 0.001)	(< 0.001)	(< 0.001)
Heteroskedasticity tests H_0 : Homoskedasticity of included instruments					
Breusch-Pagan / Cook-Weisberg χ^2 test		20.013	21.048	19.557	20.361
(P -value)		(0.274)	(0.224)	(0.298)	(0.256)

Furthermore, the models appear to be consistent with fisheries science in the sense that fishers' individual productivity are positively correlated to fishing effort (in a polynomial function of degree 2), and to the number of fishing day per week. Also significant is the gear diversity. Fisher experience (number of year operating in the fishery) or geographic sector don't appear, however, to have significant impact on the fishers' individual productivity, even if we could have expected

so¹³. Similarly, the type of species targeted does not influence in a significant way the productivity. More importantly for our discussion, the 2SLS models show that none of the four contracts has significant effect on the fishers' productivity. Even in the case of laborer (for whom the productivity appears to be relatively higher than that of the three other groups), the *t*-test shows no statistical effect.

This last analysis suggests that the existence of the complex set of contractual relationships as observed today in the fishery can not be explained by the direct impact that those different contracts have on the productivity of the various groups of fishers engaged in the fishery. Additional factors need to be considered. In the following paragraphs, we contend that one of those factors is the ability of the current contract arrangements to allow different actors to combine their own assets and/or skills with other productive resources to enter the fishery.

Access to Capital

Access to credit has been recurrently identified as a constraint to the development of small and micro enterprises in Egypt (UNDP 2004, ENCC 2006) and formal finance is often limited and fails to reach the poor (IFAD 2005, Zeller and Sharma 1998), with land ownership typically required as collateral for rural loans (Mohieldin and Wright 2000, Kruseman and Vullings 2007). *Roasa* must therefore either have enough cash to cover their initial investment and operational costs or access informal credit through their license lords. In this sense, the endowments of different actors shape the contract choice, as those with less capital are limited to those contract types which either do not require them to meet these costs upfront or those which give them access to informal sources of credit. Laffont and Matoussi (1995) describe a similar pattern among Tunisian sharecroppers, with working capital endowments shaping contract choice and accounting for the co-existence of a range of contractual forms.

While a detailed analysis of endowments of each fisher was beyond the scope of our study, we were able to identify some broad trends from the data which give us a general idea of the ways fishers in different categories access capital for investment and operating costs. Owners appear to have among the most resources of any of the categories (except labor). In addition to owning a license, nearly all of them own their own boats and gear, and are likely to have enough cash available to cover their own operating costs.

Renters also need to have cash available for initial operating costs, though they have the option to share gear or boat purchases with license lords, and several of them work with partners instead of owning their own equipment. While some renters report controlling a large number of licenses (up to 26) in their fishing camp, three out of the top five do not own the boats associated with those licenses, and a fourth shares ownership with the license lord. Most of those who own boats outright have just one or two. Renters have also the least gear per boat, which could further indicate that they have less money available for investment, as fewer of them purchase gear in conjunction with license lords, and they are responsible for a larger share of the operating costs.

Partners, on the other hand, have more gear per boat, and handle the largest fleets. This may be attributable to many of them opting to share ownership of boats and gear with license lords, as those partners appear to be in charge of more boats (on average 17.33 for those partners sharing boat ownership with license lord *versus* 5.76 for partners who own boat on their own) with more gear per boat than those who own all their equipment. Even those partners who own both boats and gear tend to have more boats (5.76 average *vs* 3.54) and more gear per boat than renters who also own boats and gear. It is plausible that some of the money which would otherwise be spent on operating costs is available to them for investment, allowing them to purchase additional gear and boats.

Those different analyses illustrate how contracts enable the partners and renters to access money for investment and initial operating costs, which would otherwise be unobtainable due to the lack

13 As some areas of the lake are more productive than others (in particular the southern part where primary productivity is higher), one might have expected a relationship between productivity and geographical sectors.

Objectives CPWF Project Report

of access to credit. On the other hand, some partners and renters are also able to access capital through their license lord who invests in boats and nets, and the majority of partners also use this relationship to partially cover their operating costs.

These different points confirm that one of the major function of the contractual arrangements as observed today in the Lake Nasser fishery –despite their relatively complexity- is to allow different actors endowed with different factors of production (licenses, fishing gears, labor), skills and capacities, to combine those assets and skills with other productive resources that lie outside their immediate possession, and to enter the fishery.

2.4. Socio-institutional analysis of Lake Volta fishery: the case of *acadjas*

2.4.1. Introduction

The previous section on Lake Nasser illustrated the importance of accounting for socio-institutional factors. We saw that both macro and micro-level institutions can have dramatic positive (or negative!) effects on the incentives and/or capacities of the actors engaged in the fisheries to improve the productivity of the system. In this section we present some related research in the case of brush park fisheries in the Lake Volta.

Adopted essentially in calm, shallow freshwater bodies such as lakes, reservoirs, tributaries and coastal lagoons, brush parks are artificial reefs made from tree branches and/or vegetation. Those low technology techniques are used to attract fish which aggregate under those 'shelters', making it easier for fishers to catch them. As such, brush parks greatly increase the efficiency of fishing operation. Spread all over the developing world (India, Bangladesh, Sri Lanka, Mexico, Madagascar) they are especially common in Africa, in particular in the Western part of the continent (Nigeria, Benin, Ivory Coast, Ghana, Togo) where they are known as '*acadjas*'.

Despite their small areas relative to the total surface of the water bodies where they are operated, those *acadjas* and brush parks can 'boost' considerably the fisheries production. The parks of the Negombo Lagoon in Sri Lanka for instance, have been estimated to contribute 35% of the total catch of the lagoon (Costa and Wijeyaratne 1994). Along the Oueme River in Nigeria, brush and vegetation parks contributed together 32% of the total annual catch and 77% of the Lake Nokoue and Porto Novo lagoon in Benin came from brush parks (Welcomme 1971). Overall, five- to ten-fold increases in catch per unit-area are not uncommon for those types of fisheries and a recent world review on inland fisheries and aquaculture indicates that well-managed brush parks can even equal semi-intensive or intensive aquaculture operations in terms of annual per-unit-area cropping rates (Sugunan et al. 2007). As such, these techniques can contribute significantly to the water productivity increase that is needed in the developing world. Brush parks represent therefore a potential option in water-bodies where they can be developed.

However, as mentioned earlier, the adoption of these techniques is not without raising a certain number of questions (both environmental and social). In particular, *acadja* and other water productivity enhancing techniques have a particularly 'bad reputation' as they are considered in many places as a potential source of tension and social conflicts between those who can develop those techniques and those who can't.

Beyond this conflict dimension –or perhaps attached to it- is also an equity issue. As in many other technical innovations, past experience has shown that those more productive techniques are not necessarily poor-neutral. They are generally adopted by the wealthier part of the communities (or sometimes by external urban-based entrepreneurs) who can afford the financial, social and institutional costs of investing in those innovations. In that context, the poorer may lose twice: firstly, because they cannot afford investing in these techniques, and secondly, because those techniques may actually affect their own access to the resources, or the return that they get from these resources.

2.4.2. Method and data

Fieldwork was carried out over a 2-month period (April - May 2007) during which 182 household interviews were completed in 10 fishing communities along the shore of the Volta Lake. Five communities with parks and five communities without parks were therefore identified and sampled. Within those 10 communities, households were then selected randomly for interview. Those households fell within one of three categories: owners of brush parks, non-owners of brush parks (in the same villages); and non-owner in villages without brush park. An individual questionnaire was administered to the head of those households, with the objective to generate information about a range of different aspects of the fishing households' economy (see Béné and Obirih-Opareh (in press) for more details).

Detailed data was collected on household assets. This included access to basic needs (running water, toilet facilities, and electric power), ownership of productive assets (fishing gear and boats, land plots, motorbike, bicycle), livestock, and other housing and general assets (TV set, refrigerator, and mobile phone). Based on these data, an individual household asset-based poverty index was computed for each household (using local market prices). Fishing assets (numbers of boats, outboard engines, and bundles of fishing nets) were also combined to compute a fishing asset index for each household. Finally, a series of 15 questions focusing specifically on *acadja* (ownership, perception, up-front investment and operational costs, etc.) completed the questionnaire.

2.4.3. Results

Some preliminary investigations suggested the potential social tensions that may emerge in fishing communities where *acadjas* are introduced. Some of the main arguments put forward by the opponents refer to potential negative externalities on both the fishing operations (e.g. reduction of the fishing ground, interaction with fishing nets) and economic activities (decrease of the market price) for those who do not own those *acadjas*. Overall, there is a feeling that *acadjas* 'increase inequity in the community'. One way to test this statement was to determine whether *acadja* owners differ from the other households in the same communities in terms of socio-economic status. Table 2.12 presents a summary of the various statistics that were generated through the survey.

We first looked more closely at the three 'wealth' indicators: the total income index, the total assets index, and the fishing asset index and tried to determine whether those indicators vary between the three groups considered in the study: *acadja* owners, non-owners, and fishers in non-*acadja* villages. The analysis shows that the *acadja* owners are better off than the non-owners and the fishers in non-*acadja* villages both in terms of income and fishing assets. The data, however, also indicates that the *acadja* owners are characterized by very high variability for the two indexes (as shown by the 95% confidence intervals on the figures), suggesting that this group is relatively heterogeneous.

Statistical tests (two-way ANOVA and Student-Newman-Keuls (SNK) tests) were run to verify those observations. As far as the income index is concerned, the test shows that despite a higher average income (7191 Ghanaian cedis (¢) for *acadjas* owners versus 3781 ¢ and 1835 ¢ for the non-owner and non *acadja* village fishers respectively -US\$1 = 9100¢) the difference in those averages is not statistically significant (ANOVA $F_{(1,181)} = 1.53$ $P = 0.218$), essentially due to the high variability of the *acadja* owner data. In contrast analysis confirms the result suggested by Fig.4.b, namely, that the fishing asset index of the *acadja* owners is higher than that of the two other groups ($F_{(1,181)} = 13.99$ $P < 0.001$, $q_c = 5.29$).

In short, the results from this comparative analysis highlight the following points: *acadja* owners seem to be better endowed in terms of fishing assets (engines, boats, nets) than the other fisherfolks in the same *acadja* villages or in non-*acadja* villages. Those *acadja* owners also seem to have higher total income per household (as suggested by the data in Table 2.12). On the other hand, *acadja* owners do not seem to be better endowed than the non-owners in the same villages in terms of assets.

Table 2.12. Statistics summary of the socio-economics data [95%CI].

	<i>Acadja</i> owners (N= 33)	Non-owners in <i>acadja</i> villages (N= 85)	Households in non- <i>acadja</i> villages (N= 64)
Household size	9.9 [1.77]	8.79 [1.49]	8.9 [1.20]
Livelihood diversification ^(a)	3.84 [0.49]	3.75 [0.23]	3.04 [0.23]
Female headed household	3.03%	5.65%	5.90%
Literacy rate ^(b)	30.3%	41.5%	38.9%
Number of year since settlement	11.4 [3.1]	14.9 [2.0]	18.3 [2.9]
Access to running water	3.0%	4.7%	0%
Access to electric power	66.7%	71.8%	53.1%
TV set ownership ^(c)	54.5%	41.2%	18.8%
Cell Phone ^(c)	21.2%	40.0%	39.1%
Refrigerator ^(c)	30.3%	28.2%	9.4%
Fishing gear ownership ^(d)	100%	88.2%	92.2%
Number of boats per household	1.81 [0.84]	1.07 [0.22]	1.25 [0.20]
Number of outboard engines	1.67 [0.92]	0.67 [0.20]	0.18 [0.13]
Income dependence on fish ^(d)	94.2%	97.4%	92.2%
Household total income Index ^(e)	7192 [5862]	3781 [1280]	1835 [573]
Household Income per boat index ^(e)	3350 [2061]	3260 [1179]	1550 [538]
Household assets index ^(e)	11500 [6152]	10440 [3895]	5380 [1560]
Fishing assets index ^(e)	5850 [2951]	2980 [7234]	2530 [508]
Gini Coefficient G	0.89	0.83	0.78

Notes: (a): number of activities in which the household is engaged; (b): number of illiterate household heads; (c) number of household owning at least one unit; (d) percentage of household owning their own fishing gear; (e) percentage of households declaring fishing related activities (fishing, fish processing, fish trading) as their main source of income; (e) in ¢ per household.

In a subsequent analysis we investigated the potential economic inequity associated with *acadja*. This issue had already surfaced several times in the course of the analysis; firstly, during the preliminary analysis, when non-owners of *acadjas* were denouncing the fact that *acadjas* 'increase inequity within the community' -which would suggest an inter-group heterogeneity (between owners and non-owners); secondly, during the economic analysis above, when we noted that the group of the *acadja* owners was systematically displaying a higher statistical variance than the two other groups -suggesting an intra-group heterogeneity.

To investigate those hypotheses we computed the respective Gini coefficients for each group (owners, non-owners and other fisherfolks in non-*acadja* villages), as well as for the aggregate group (owners + non-owners in the *acadja* villages), using the household total income index. The results of those different computations are displayed in Fig.2.8. The figure shows that *acadja* owners is the group with the highest level of income inequality (G = 0.89), followed by the non-owner group (G = 0.83) while the fishers operating from non-*acadja* villages have a lower inequality index (G = 0.78). When combined together the aggregate group (owners + non-owners of *acadjas*) display a Gini coefficient of 0.86.

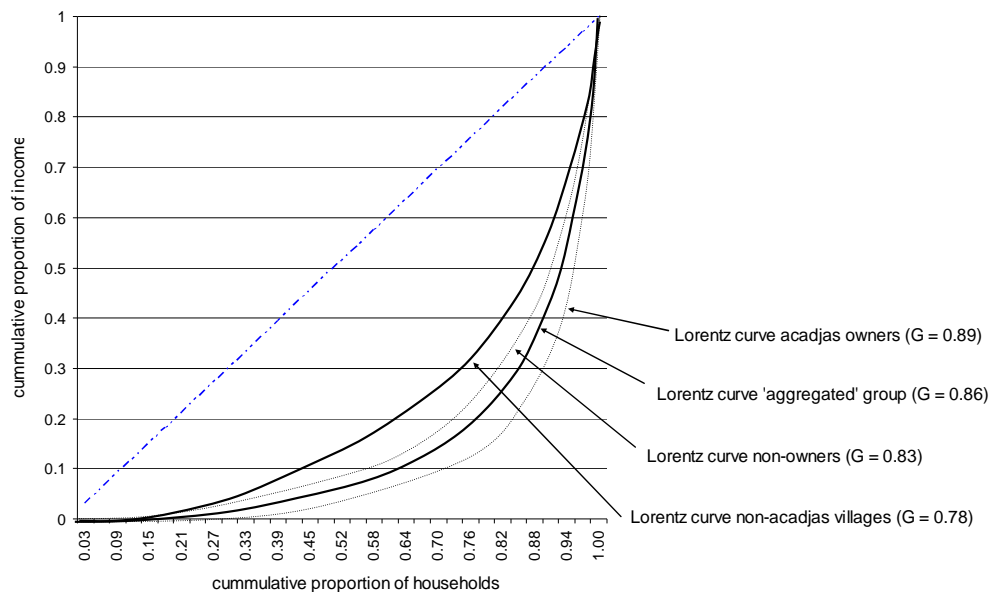


Fig.2.8. Lorenz curves and Gini coefficients (G) computed for the four groups: owners, non-owners, non-*acadjas* villagers, and 'aggregated' group (owners + non-owners), based on the total income data.

Those last results corroborate both hypotheses of intra and inter-group inequities. They confirm in particular that the high intra-group variance observed for the *acadja* owners was indeed due to a high inequality of income within the group. But the results also confirm what the opponents of *acadja* have claimed: inequity is higher in villages with *acadjas* than in villages without *acadja* – even if the average income or assets indexes are lower in villages without *acadja*.

In line with the inequity analysis above, we investigated whether *acadja* is a 'poor-neutral' technology. For this, we looked at where *acadja* owners are located along the community income ladder, determining in particular what proportion of them belongs to the poorest half of the community (i.e. the quartiles Q_1 and Q_2) as opposed to the 'wealthiest' half (Q_3 and Q_4). In addition, we compared within each quartile Q_i the income of those *acadja* owners with the income of the rest of the population in the same quartile. For this the ratios $R^{Q_i} = I_O^{Q_i} / I_P^{Q_i}$ with $i = 1, \dots, 4$, was computed, where $I_O^{Q_i}$ is the average income of the *acadja* owners and $I_P^{Q_i}$ is the average income of the rest of the population in the same quartile Q_i . In short, a ratio $R^{Q_i} > 1$ would suggest that *acadja* owners are better off than the other households in the same quartile, while a R^{Q_i} close to 1 for all quartile would suggest that *acadja* are poor-neutral.

The data showed that *acadja* owners are found in all four quartiles. A greater proportion of them (57.6%), however, belong to the two wealthiest quartiles of the population Q_3 and Q_4 . This tendency was confirmed by the rest of the analysis (Fig.2.9). The ratios R^{Q_i} show that the *acadja* owners of the 4th quartile (the richest part of the population) are twice as rich as the other households in the same quartile ($R^{Q_4} = 1.98$). This effect is also observable for the 3rd quartile where *acadja* owners are on average 15% richer than the other households in the same quartile ($R^{Q_3} = 1.15$). In contrast, for the poorest part of the population (quartiles Q_1 and Q_2), *acadjas* do not seem to help their owners to generate higher income than to the rest of the population. In fact, *acadja* owners in the poorest quartile are actually slightly poorer than the non-owners ($R^{Q_1} = 0.89$). In brief, *acadjas* appear to be effective in boosting the incomes of the richest owners, but failed to have the same effect on the poorer owners, indicating clearly that *acadja* is not a pro-poor, or not even a poor-neutral, technology.

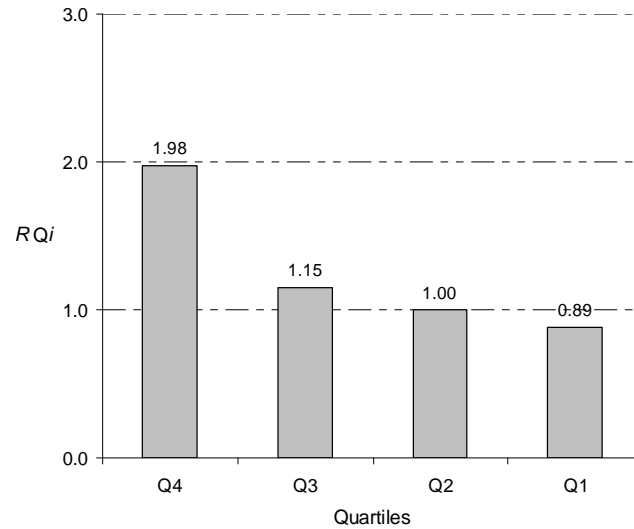


Fig.2.9. Comparison of the incomes of *acadja* owners with the rest of their respective quartile population using ratios R^{Q_i} (see text for calculation detail). Q_1 = lower quartile, Q_4 = higher quartile.

2.4.4. Discussion

Brush parks have been recognized to be a relatively efficient fishing technique to enhance fisheries productivity, and as such could contribute effectively to increase food productivity in the rural areas where they are adopted. The development of those brush parks appear, however, relatively controversial, as they are frequently recognized to be a form of enclosure of the commons and, as such, to create intra-community conflicts and increase inequity.

Our analysis showed that the impact of *acadjas* on the fishing communities of the Lake Volta is mixed. There is evidence that this technique probably helps enhancing the supply of protein-rich food to the (local) communities where they are introduced -and possibly to the more distant urban areas (e.g. Accra and Kumasi). Combined with a possible reduction in fish price, this increased in fish supply may contribute to improve consumers' food security.

Those positive contributions to food security and local economic growth appear, however, to be greatly reduced by other more negative effects associated with the establishment of *acadjas*. Our analysis showed in particular that *acadjas* are certainly not pro-poor and probably not poor-neutral either in the sense that their contribution to household income appear to benefit disproportionately the wealthier owners. The analysis also showed that *acadjas* increase economic inequity in communities where they are adopted.

2.5. Section 2's General Discussion

The larger bulk of the scientific effort published so far in the literature in relation to reservoir fisheries focused essentially on the bio-physical and ecological parameters (depth, areas, primary productivity, etc.) of those reservoirs and the way those parameters affect fishery productivity.

In contrast, very little is known about the social, economic, or more broadly institutional processes related to the process of enhancing reservoir fisheries productivity. Yet, the few analyses that are available (e.g. Ali and Islam 1998 Capistrano et al. 1994) suggest that those socio-institutional factors are critical in shaping the way enhancement technique are adopted, disseminated or in contrary rejected by fishery actors. For instance, it is usually assumed that the identity of the leasee (private entrepreneurs, groups of fishers, or cooperatives) who is entitled the fishing and

management rights over a specific water body, has usually an important influence on the overall production level of that system. Through his investment or management decisions (e.g. regarding the stocking intensity or level of fishing effort) and his capacity to organize and monitor fishing activity over the water-body he controls, the leasee has the capacity to modify substantially the production level or even the productivity of the reservoir. In that regard, collective groups and cooperatives are often viewed as affected and constrained by collective actions or CPR issues such as free riders behavior (Sargeson, 2002), leading to underinvestment and/or misallocation of resources. In contrast, private contractors –due to their greater financial capacity and supposedly greater entrepreneurial skills- are expected to be more 'effective' or more 'successful' in managing and exploiting enhanced reservoirs.

Our results in India suggest a more complex and subtle reality. Due to their more robust financial capacities, private contractors are generally able to outcompete cooperatives and/or groups of individual fishers at the auction stage and thus to acquire leasing rights over the most productive (small, shallow) reservoirs. As a consequence, cooperatives are often left with the remaining larger, deeper (and less productive) reservoirs. Thus the low productivity characterizing cooperatives-managed reservoirs is more often the consequence of the bio-physical characteristics of the reservoirs (in particular the higher depth of the water-bodies leased by those cooperatives) than a real lack of management efficiency or investment. The CP34 data for instance show that cooperatives do not necessarily stock lower quantities of fries than private entrepreneurs. This result directly challenges the view that collectively managed resources systematically lead to under-investment. In addition to selecting naturally more productive reservoirs, private contractors are also able to purchase larger fingerlings (thus more likely to survive) than the smaller (and cheaper) fries purchased by cooperatives.

In Egypt, our analysis focused on another important aspect of fishery institutional setting: the remuneration contract that binds together the different actors engaged in the fishery (license owner, fishing gears owners, and laborers). In Lake Nasser fishery, like in a large number of other fisheries in developed and developing countries, remuneration is determined by some forms of share contracts (Platteau and Nugent 1992). In this context, the objective of our research was to determine whether a thorough understanding of those remuneration contracts could help us unfold some of the functions provided by what appeared to be a relatively complex contractual system. Of particular interest was the question of whether those various contracts have an influence on the productivity of the individual fishers. Statistical analysis revealed however that the combination of complex contractual arrangements that exists between license owners, fishing gear owners and laborer (boat crew members) does not seem to influence directly the level of productivity. In particular, no correlation was found between the types of contract and the level of productivity observed at the individual fisher level.

Instead, we postulated that, in absence of formal or efficient local capital and/or cash credit institutions, another major function of this complex set of share contracts is to allow different groups of actors who do not necessary possess all of the capital and resources necessary to engage in the sector, to combine their individual resources with others agents and put them into productive use. One of the most important functions served by the Lake Nasser fishery contracts is therefore that of mobilizing capital for investment and operational costs.

Institutions or policies may not, however, always provide positive incentives for individual or collective behavior. They can also, in certain circumstances, create counterproductive environment which will, in the long-term, greatly limit the sound development of a specific economic activity. That is what has been observed in the case of the Lake Nasser fishery where our research showed how the combination of inadequate policies and economic and management tools have led to the creation of a massive black market. Some of these negative incentives include the imposition a fixed price for fresh fish and the limitation of the number of license to 3000, forcing de facto 3000-4000 fishers to operate illegally. As a consequence it is estimated that today about 50% of the fishery production is smuggled and commercialized through a parallel market.

In Lake Volta, we looked at the other 'side' of the problem by investigating on how technical innovations (in this particular case, brush park *acadjas*) influence some of the economic and social

Objectives CPWF Project Report

features of the locale communities. The data show that while *acadja* increases fish supply, reduce fish price and therefore improve fish food security at the local –and possibly- national level, it also reinforces the economic inequity in the community. Besides, because it is a form of privatization of the commons, *acadja* is often seen –or perceived- as a source of tension between the owners and non-owners of these *acadjas*.

Those last results are in line with other studies where enhancing fisheries programmes had been successful in increasing the total production of the fisheries but failed to improve the well-being of the poorest in the communities (e.g. Ahmad et al. 1998, Apu and Middendrop 1998).

Policy Implications

In each of the three countries considered in this analysis (Ghana, Egypt, and India), recent changes were introduced in policies in direct relation to some of the issues discussed above. A brief analysis highlights some of the potential incoherencies or difficulties that these new policies are likely to face.

In Egypt the local law which had been imposing a fixed price on fresh fish for more than 45 years has been abolished recently (Oct. 2008). This new policy, which was passed in an attempt to curb the smuggling, did not bring so far the expected outcome. Although some may argue that it may be too earlier for this change to happen, there are strong reasons to pre-empt that this policy (although necessary) will not be sufficient to ensure the disappearance of the black market. Some of the reasons for this include:

- The limited number of license. As the regulation limiting the number of licenses has been maintained, a large number of fishers (approximately 3000 to 4000) are still operating illegally (i.e. without license) on the lake. These fishers are not authorized to land their catch on the official landing harbors. The black market is therefore for them the only option to continue selling their catch.
- Under-sized catch. An unknown (but probably non-negligible) proportion of the fish is caught under-sized (i.e. smaller than the size limit imposed by the authority). The black market offers an opportunity for fishers to sell their under-sized fish that would otherwise be seized if landed at the official landing harbors.
- Institutionalization of the black market. The black market has now becomes such an institution, deeply entrenched in the local and national economy (with ramification all the way from Aswan down to Cairo), that it will take years to eradicate it. Too many people (fishers, fish-traders, fish retailers) are now depending upon it.
- Faced with this plague, the authorities have chosen to toughen the military control on the water and the shore of the lake. Patrolling such a large lake (the second largest in Africa) and its 7000+ km of beach is not however without costs, risks and problems. Perhaps a more effective way to reduce the smuggling would be to release the number of license. This, however, would certainly face some opposition from the current license owners (mainly from the local elite) who benefit from the rent created by the current status quo.

Finally note that eliminating this black market would not necessarily have a direct, positive, impact on the productivity of the lake, but may instead simply enable scientists to gain a better appreciation of the current production level of the lake in relation to its potential.

In Ghana, the contrasting position adopted by the government regarding *acadjas* on one hand and cage culture on the other is worth noticing. While the central authorities clearly do not encourage the development of *acadja* -local authorities (District Assemblies and fishing associations) have been advised to discourage *acadjas*-, they strongly support cage culture. As part of this policy, one percent of the total surface area (8,700 km²) of the lake has been allocated to the development of cage aquaculture. Yet, cage culture and *acadja* are comparable in many respects relevant for our initial consideration:

- they can both increase fish-supply and therefore contribute to improve consumers' food security

- they are both a form of privatization of the commons, and documented evidence exists about the potential social tension that they both can create locally.
- They both are not poor-neutral in the sense that they benefit wealthier entrepreneurs.

The major difference lies in the investments requested to run those two activities. It takes about 10 times more (approx US\$5000) to build up a cage while only US\$500 are necessary to build up an *acadja*. Besides, because *acadja* does not require as much management and daily technical attendance that cage does, it allows household to engage in other parallel activities. *Acadja* is already widely spread and adopted in the region. Those apparent advantages question the coherence of the authorities in their choice to support cage culture.

In India, while the authorities have recognized the strong contribution that reservoir fisheries can play in poverty alleviation -in particular for the rural population living in the vicinities of those reservoirs-, they are also clearly aware of the important potential of those reservoirs as sources of cheap fish-supply for the growing urban populations. The National Fisheries Development Board is therefore now actively supporting reservoir fisheries development, in particular through loan facilities. Those supports, which are available for seed purchase, are poor-neutral: they do not target specifically cooperative or poor communities but are instead available to anyone (private contractors, cooperative, informal groups of fishers) who is willing to invest in fisheries activities. Clearly the priority is on supporting effective production of food. More 'pro-poor' support exists, however, through for instance the provision of a 25% subsidy proposed specifically to cooperatives during the auction procedure.

2.6. Section 2's Conclusion

The objective of the second main component of the project was to investigate the socio-institutional and economic dynamics of some of the different processes associated with fisheries reservoirs and to explore in particular the potential links that exist between those socio-institutional processes and the capacities of the local actors to engage in technical innovations in relation to increased reservoir productivity. The results of CP34 research do not simply confirm the importance of institutions in shaping the economic and social inter-actions occurring in fishery activities in general (something which is already well established). They also stress the role that those institutions play in determining which technological option(s) can be considered and adopted, and how this adoption is likely to impact on the various groups in the population.

Where academics or even fishery managers are used to see practical problems 'fixed' by technical solutions, this part of the research remind us that even those practical problems and technical solutions are often the results of specific institutional contexts or macro-economic policies. In other words, the issue is often not technical (we know how to build a small-scale cage), but institutional (what are the social or economic factors that prevent the local populations from adopting this small-scale cage technique?).

Those reflections highlight the necessity to continue to combine social, economic and policy analysis with the more conventional ecological and bio-physical approach if we are intended to improve our capacities to engage with and support local populations and governments in their attempt to improve the productivity of tropical reservoir fisheries.

Section 3: Strengthening stakeholders' capacities

3.1. General introduction

One of the greatest constraining factors to the adoption of (technical or institutional) innovations is the limited organizational and institutional capacities of the poor. Both at the individual and collective levels, the ability of those destitute households to engage with innovation and changes is often more limited than the capacities of the better-off people in the same environment (due to a better education, a better human capital, a higher risk-aversion, etc.). A great part of the

Objectives CPWF Project Report

recurrent effort of CP34 was therefore to address this low capacity. In particular, the third component of the project was aimed at facilitating the implementation of the fisheries productivity interventions selected in each sites by improving the stakeholders' management skills and fostering their institutional capacities. This was done through a variety of activities. In particular:

- A series of 8 'capacities strengthening' and 'community consensus' workshops were conducted in parallel in each of the 3 basins during the course of the project.
- Post-harvest interventions were conducted in the 4 reservoirs with the objectives to improve the post-harvest fish processing or to strengthen the capacities of the actors involved in those post harvest activities.

3.2. Scheduled workshops

Two series of four 'capacities strengthening' and four 'community consensus building' workshops were conducted (Photos 3.1), with the specific objective to address capacity issue. The two series were implemented in the three basins as follows (Table 3.1).



Photos 3.1. Consensus building workshops in Pahuj (left) and Aswan (right)

Table 3.1. Series of workshops run by the projects as part of the capacity building objective.

Volta Basin	Date	Location	Specific objective
Capacity strengthening			
Workshop No.1	12 May 2005	Accra	Introduction of CP34 to NARES & other stakeholders. In Volta Lake (eg VRA, EPA & VBRP)
Workshop No.2	16-17 October 2006	Dzemeni	Strengthen capacity of (woman) fish processors and traders
Workshop No.3	28 June 2006	Kpeve	Entrepreneurship training for fish smokers and traders
Workshop No.4	Hold in combination to Consensus building Workshop No.4	Kayira in South Dayi District and Kpeve-Tornu, in Hohoe District	Issues of resource management and increased productivity
Workshop No.5	28 Aug 2007	Tsokome, near Accra	Fish smokers to practically evaluate performance of Chokor smoker and New FRI
Consensus building			
Workshop No.1	22 March 2006	Dzemeni	Introduction to the project main objective
Workshop No.2	Oct-Dec 2006	Series of 'low-key' consensus building meetings organised in various communities around Dzemeni	Sensitization to issues of productivity enhancement

Workshop No.3	26 Feb 2008	Dzemeni	Discussion with fish smoking group (fish processors)
Workshop No.4	04 April 2008	Kayira in South Dayi District and Kpeve-Tornu, in Hohoe District	Issues of resource management and increased productivity
Nile Basin	Date	Location	Specific objective
Capacity strengthening			
Workshop No.1	02 Jan. 2006	Aros El Nile	Sensitization to fishery management issues
Workshop No.2	19-20 Sept 2006	LNDA Offices	Discussion on Lake fishery management and obstacles to improve production
Workshop No.3	9 May 2007	LNDA Offices	Up-dating on enclosure experiments progress
Workshop No.4	28 Feb 2008	LNDA Offices	Discussion around the issue of fish smuggling
Consensus building			
Workshop No.1	29 May 2006	LNDA Offices	Identification of the main problems in Lake Nasser
Workshop No.2	14 Nov. 2006	LNDA Offices	Introduction to enclosure as a fishery enhancement technique
Workshop No.3	12 August 2007	LNDA Offices	Up-dating on enclosure experiments progress
Workshop No.4	17 June 2008	LNDA Offices	Up-dating on enclosure experiments progress
Indo-Gangetic Basin	Date	Location	Specific objective
Capacity strengthening			
Workshop No.1	Dahod Reservoir on 6 June 2006 and NRCAF, Jhansi on 9 June 2006		Culture-based fisheries enhancements
Workshop No.2	Dahod Reservoir on 22 June 2006 and NRCAF, Jhansi on 29 August 2006		Introduction to pen and cage culture as productivity enhancement techniques
Workshop No.3	Dahod Reservoir on April 27, 2007 and Pahuj Reservoir on August 21, 2007		fish marketing and concept of micro-finance
Workshop No.4	Dahod reservoir on October 3, 2007 and Pahuj reservoir on October 20, 2007		To apprise fishers about the package and practices for fish seed raising in cages
Consensus building			
Workshop No.1	June 7 at Dahod and 10, 2006 at Pahuj		Fisheries enhancements to be adopted under project
Workshop No.2	June 20 at Dahod and June 22 at Pahuj 2006		Identification of viable enhancement model
Workshop No.3	July 23, 2007 at Dahod Reservoir and on August 22, 2007 at Pahuj		Progress on the project pen and cage culture trials
Workshop No.4	16-17 May 2008	Jhansi	Progress of the project on interventions made for production enhancement

3.3. Post harvest interventions

3.3.1. Improving fish processing in Lake Nasser

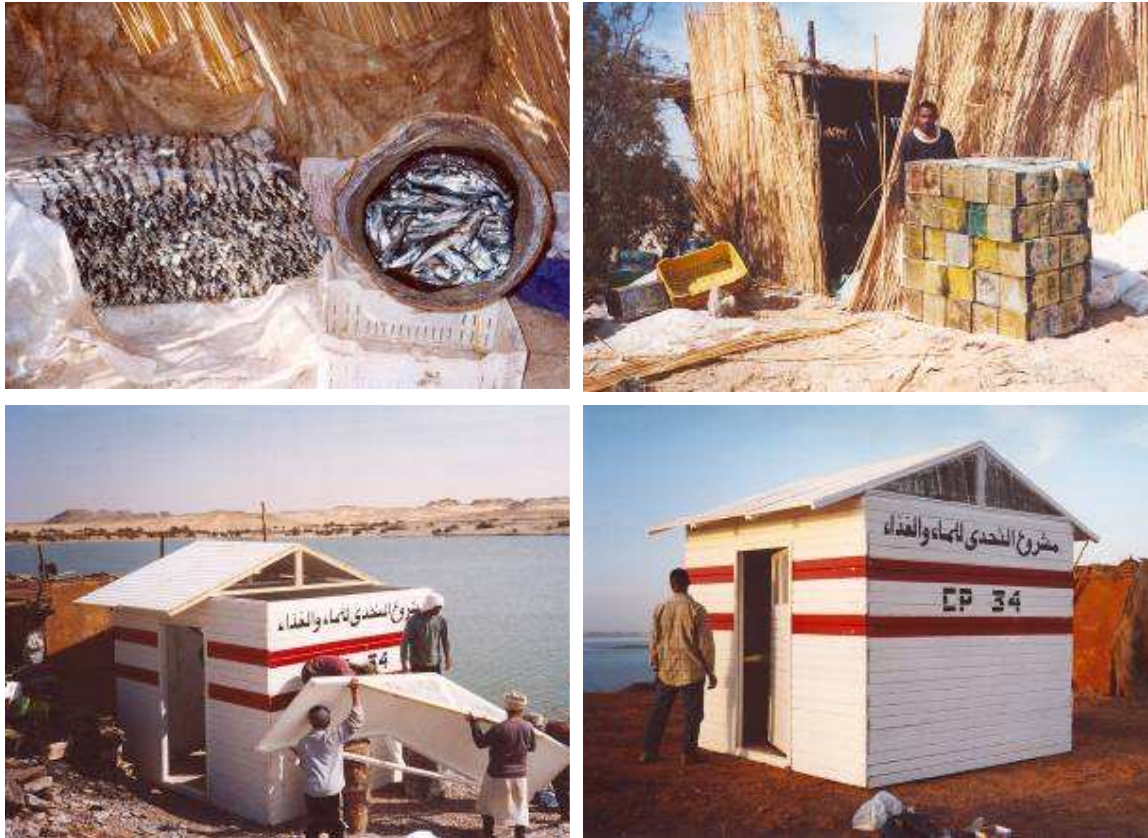
The context

Enclosures were not the only interventions considered in CP34 to increase the productivity of the Lake Nasser fishery. The Lake Nasser Development Authority, following series of consultation meetings with the fishers embarked into an attempt to improve the quality of the salted fish produced in the fishing camps. The idea was to provide 'wooden houses', that is, small low cost wooden cabins, where the salting procedure could be completed while improving the hygienic conditions of the operation.

The two main species used for salted fish are Kalb El Samak (*Hydrocynus forskali*) and Raya (*Alestes sp.*) which together represent about 10-25% of the total catch. Traditionally the conventional salting technique is conducted as follows: the fish to be processed are exposed to direct sun to be dried in open air for about 24 hours. Large size fish are then gutted before being salted, while small fish are salted whole. Salt is placed in the fish abdomen cavity while another thick layer of salt is spread on the outer surfaces of the fish. Salted fish are then stored inside a

Objectives CPWF Project Report

hole in the ground or in clothes and placed in a primitive container. After a drying period of 3 to 5 days, the fish are packed into tins (Photos 3.2). The tins are then covered with plastic and transported to the markets where they are sold. Each tin weighs approximately 27kg and its value fluctuates around EGP 650 (EGP 25/kg). The fish are ready for consumption after 1-3 months.



Photos 3.2. Top: traditional salting technique: fish are partially sun-dried, slated and then stored into clothes or primitive containers for 3 to 5 days. The whole process is however operated in open air, favoring bud, fungi, and bacterial infestation. Bottom: three wooden houses built up on site to allow for salting operations to be completed in improved hygienic conditions

Three wooden cabins were manufactured and assembled on site (Photos 3.2), with an overall cost of approximately EGP7000 per cabin (Table 3.2). Each cabin was equipped with mosquito nets on its openings and a specially designed container which allows the residual liquid from the salting process (water, blood) to be evacuated. The objective was to reduce the insect infestation and improve the general hygienic condition during the salting process. In addition, adjustments were proposed for the use of recyclable containers (in which gutted fish are heeled with salt) in an attempt to reduce cost while improving quality of product.

Table 3.2. Aggregated cost of the wooden cabin (for the 3 cabins)

Wood	Paintings	Manufacture	others	Total
12491	5240	2664	594	20989

Statistical analysis

Batches of tins processed inside and outside the cabins by the fisheries were sampled for the three sites over the period Jan 2007-Dec 2008. A total of 2748 tins constituting 54 batches (29 inside

and 25 outside) were thus sampled. The number of spoiled tins inside and outside was recorded (Table 3.3). Non-parametric statistical tests (Mann-Whitney Rank Sum Test) showed that the proportion of spoiled tins proceeded inside the cabins was statistically lower than outside (Table 3.4 and Fig.3.1).

Table 3.3. Number of spoiled salted fish tins

Number of tins	proceeded		spoiled	
	inside	outside	inside	outside
Winter	70	64	0	1
Spring	552	219	2	6
Summer	431	285	2	7
Autumn	567	560	2	10
total	1620	1128	6	24

Table 3.4. Mann-Whitney Rank Sum Test

Normality Test:	Failed	(P = <0.0001)			
Mann-Whitney Rank Sum Test					
Group	N	Missing	Median	25%	75%
Inside	29	0	0	0	0.00808
Outside	25	0	0.02	0.01	0.02425
T = 946.0 n(small)= 25 n(big)= 29 (P = <0.0001)					

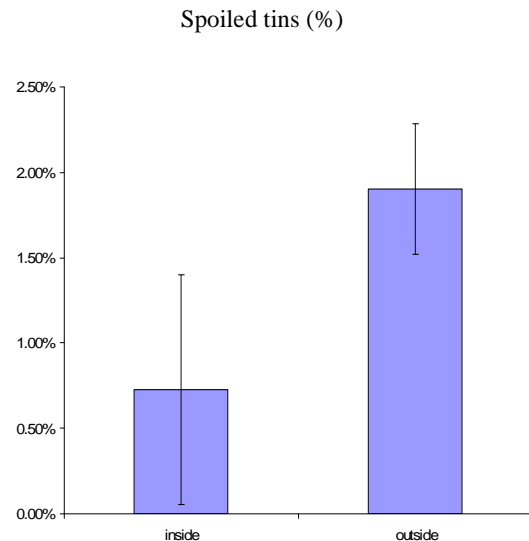


Fig.3.1. proportion of tins spoiled inside and outside the wooden cabins (95% CI)

Discussion

The data collected over the 2-year survey period by the CP34 confirms the positive effect of the wooden cabins on the salting process. Completing the fish processing within the cabin decreases significantly the proportion of salted fish spoiled during the process. Unfortunately it was not possible to determine whether the use of the cabin also altered (positively) the price at which the salted fish are then sold at the harbor (as no price data could be collected). Given that the difference in number of spoiled tins is 18 out of a total of 2748, assuming no change in the unit price of the tins (approx. EGP 675/tin), the financial value lost for 1000 tins is EGP 4420, which represents only 0.66% of the total value (worth EGP 765,000). Note however that the total value of those 18 tins that were 'saved' from spoiling through the use of the wooden cabin is EGP 12,150 over 2 years, meaning that the cost of the 3 wooden houses (EGP21,000) would be recovered in less than 4 years. The group of local fishers who benefited from the wooden houses have advised the project to increase the size/capacity of the house in order to facilitate the process of an increased amount of salted fish.

3.3.2. Improving fish trading in India

Provision of ice-box and transportation

One of the major problems in fish disposal is access to the reservoir and maintaining quality of fish before its disposal. To solve these problems market and transportation support was provided to the Fisherman Cooperative Societies in the form of six bicycles fitted with iceboxes in the two reservoirs in India where CP34 operated (Photos 3.3). The market survey and opinions of fishers and market intermediaries revealed good impact of the intervention (Photos 3.3 and Table 3.5).



Photos 3.3. Left: bicycles fitted with iceboxes to improve quality of fish during transportation. Right: Market survey.

Table 3.5. Comparative analysis of production level and retail price before and after CP34 intervention

Fish category	Production (t)		Average retail price (Rs/kg)	
	Pre project	Post project	Pre project	Post project
Major carps	5.47	11.14	45.00	75.00
Catfishes	5.35	4.98	50.00	98.00
Miscellaneous	6.68	5.93	20.00	51.00
Total	17.5	22.06	34.93	73.70

The fishers were also suggested to operate collectively to reduce cost of transportation, storage and marketing and better bargaining for price negotiations with the local dealers. The fishers are now able to transport their catch promptly and in good condition, which increases the remuneration of their catch (Table 3.6).

Table 3.6. Comparative analysis of catch and return per unit of effort before and after CP34 intervention

Fish category	CPUE (kg)		Individual returns per unit of effort (Rs)	
	Pre project	Post project	Pre project	Post project
Major carps	3.95	4.23	239.21	317.48
Catfishes	3.87	1.89	216.08	185.23
Miscellaneous	4.83	2.25	101.50	114.78
Total	12.64	8.38	556.79	617.50

Establishment of a micro-finance system

Another part of the CP34 activities centered on the establishment of a self-financing system. To establish this system, fishers were suggested to:

- Form a saving/micro-finance unit under control, supervision, guidance and monitoring of SFD and State Department of Co-operatives
- Promote and do small savings in form of compulsory contributions at the time of receiving the remuneration for their fish catch

- Create awareness amongst the fishers of the SFD's current saving scheme policy that consists in contributing an equal matching fund to fisher's account, if the latter raises some funds. This policy is thought to provide additional incentive for fishers to save and raise their own finance.

A self-finance system was therefore established in Dahod, with the opening of a saving bank account at the local bank, namely, Satpura Kshetriya Gramin bank, Nurganj in the name of co-operative society - Narmada Matsya Palan Sahkari Sanstha, Nurganj. Eighteen members of the society have been depositing Rs 50 every month since December 2008, with an equal matching amount deposited by the project as part of an incentive for further savings.

3.3.3. Improving fish processing in Ghana

Background

Fish smoking has always been a major fish post-harvest approach to conserve and add value to some fish in developing countries in Africa. Thus technology to improve it remains on the agenda of appropriate institutions such as the CSIR-FRI, Ghana. During the past two decades the most significant improvement related to fish smoking involvements in the Africa region has been the introduction of the Chorkor Smoker. It was initially developed at the fishing community of Chokor, a suburb of Accra in Ghana, but is currently used in several countries in Sub-Sahara Africa. Major advantages of the Chorkor –Smoker over the traditional oven included the following:

- Increase smoking capacity;
- more efficient use of fuel wood;
- reduced contact between layers of fish being smoked on same oven;
- elimination of need to manually turn fish to have two sides of fish smoked; and
- reduction in attendance by (women) smokers, thus reduced exposure to smoke and heat and their related health implications.

Involvement of CP34

During the initial six months of the project, a participatory assessment exercise conducted in Dzemeni on the shores of the lake revealed the necessity to search for an improved fish smoking technology. A need to improve on parking of fish from smoking centers to markets was also identified. Following this, a half-day workshop on fish smoking involvements (as cooking, drying and flavoring) and functioning characteristics of available smoking ovens, especially the 'Chorkor-Smoker' was organized on 28 June 2006 under the leadership of a Post-Harvest researcher from CSIR-FRI, Ghana. The objective of the workshop was mainly an introduction and evaluation of a new fish smoking oven, called the 'FRI-Smoker', considered to be an improvement over the Chorkor-Smoker. Both the Chorkor – and the FRI-Smokers are products of the CSIR-FRI.

The current project's search for an improved fish smoker necessitated a liaison with the CSIR-Food Research Institute's working Group on the subject. The linkage recently, informed the CP34 of the construction of a 'FRI-Smoker' by the CSIR-FRI with support of the Food and Agriculture Organization (FAO) at another suburb of Accra, Tsokome. Leaders and representatives of four fish smoking groups or associations from Dzemeni were assisted to travel to Tsokome where the nearest of the only two of FRI-Smokers currently is situated (Photos 3.4 a-d).

The activity of fish smoking was reviewed. Functional characteristics of the two smokers and the relative status of smokers, after discussion are indicated in Table 3.7 (directly transcribed from the women processors meeting). The visit and technical discussions which ensued encouraged fish smokers in project pilot areas to initiate self-financed activities to acquire the new oven for groups of fish smokers. A local NGO decided to disseminate the new oven to other fish smoking communities.

Objectives CPWF Project Report



a. Chokor Smoker with a pile of trays to contain fish for smoking. Openings for fuel wood directly under fish.



b. FRI-Smoker showing shelves as they would be positioned with Fish to smoke. Openings for fuel wood on side of trays holding fish



c. Groups of participants discussing fish smoking and the two smokers



d. Sample of workshop smoked fish

Photos 3.4. Chorkor-Smoker and FRI-Smokers

Table 3.7. Characteristics of the two fish smoker ovens (directly transcribed from the processors meeting)

Characteristic	The chorkor-smoker	The FRI-smoker
1. Costs of Construction	Lower	Higher
2. Relative position of fuel-wood heat and fire to fish being smoked	Directly under fish	From side chambers to fish position
3. Fuel wood energy utilization	Relatively more escape through smoker walls and top of smoker	Relatively more retained in smoker. No escapes through walls and minimum escape with smoke through chimney, which could be closed
4. Time availability to person engaged in smoking	Even where approximate time required for rearranging trays to have fish completely smoked could be estimated smoking require attention	Where approximate time required could be estimated person involved could be completely engaged in another activity till fish smoking is over.
5. Exposure of person smoking to heat and smoke	Persons smoking and around smoking area exposed to smoke and heat.	Persons smoking fish and around free from heat and smoke.

6. Product appeal for potential market value tag	<ul style="list-style-type: none"> • Less evenly smoked. • Could have burns because fish fat could drop onto fuel wood and set flame. • Product dry and less appealing. 	<ul style="list-style-type: none"> • Evenly smoked • Can not have burns because fat from fish eventually falls to floor of smoker as fire is on sides. • Product not dried up but glossy and appealing
--	--	---

3.4. Section 3's General Discussion

The project undertook capacity building of primary fisheries stakeholders in the three basins covering several areas of fisherfolk activities.

Sensitization: reference to sustainable utilization of fish resources, advocacy for use of authorized or approved mesh sizes of fishing nets, capture of approved sizes of fish species were highlighted during the formal (e.g. workshops) or informal (conversation) interactions with the communities. Observation of closed fishing seasons was advocated. Reference to conservation of other fisheries resources, advocacy against destructive fishing gear with respect to spawning and nursery grounds were also done. Debates and sensitization discussions were conducted on food quality issues and the advantages of using ice during fishing expeditions and marketization.

Post harvest activities: To improve the preservation of captured fish, capacity of primary fisheries stakeholders were strengthened in all three basins. In the Volta basin, basic entrepreneurship training was provided to fish traders and smokers. Capacity building was aimed at enhancing quality of fish and processed fish. Emphasis has been put on enhancing knowledge of fish smokers of fish-smoking regarding cooking, drying and fish flavoring processes. As part of this process, the project partners identified an advanced fish smoking oven that was thought to produce an improved quality product for higher market value, reduce health risk for fish smokers and allow fish smokers to engage in other parallel (domestic or out-of-house) activities during the smoking process. In India the emphasis was on building fish-traders' capacity in understanding relationship between fresh fish quality and price. The project piloted assistance to transport fish in ice boxes on bicycle over the 10 km distance between the reservoir and the local market. Net result included increase in fish price from 35 Rs kg⁻¹ to 74 Rs kg⁻¹. Soon after, the project helped the fishers to establish a self-financing scheme and facilitated the establishment of a micro-credit scheme to advance project gains. In Lake Nasser the project aimed at improving the capacity of salted fish processors to enhance production and quality of their products through the use of wooden houses specifically designed to reduce fish exposure to insect infestations. The houses were shown to improve the quality of the salting process.

3.5. Section 3's Conclusion

In small-scale fisheries (in particular in tropical countries with high temperature, humidity and risk of insect infestation), capacity building interventions associated with post harvest losses are likely to produce immediate and measurable impacts. The project demonstrated that increased capacity of fisherfolk in appropriate low-cost post-harvest technologies can reduce fish post harvest losses (fish spoil) greatly and have positive impacts on food quality. Possibly, this can also contribute to improve resource conservation by increasing incomes of fisheries dependant communities through two complementary mechanisms: (1) quantity-effect: as the post-harvest losses are reduced, the total quantity sold increase, thus increasing the total revenues, and (b) price-effect: as the quality of the fish processed increases, the unit price of the product is also likely to increase.

Beyond those direct, tangible interventions on post-harvest and fish trading issues, a greater part of the capacity and consensus building activities undertaken by the CP34 focused on -perhaps less measurable but certainly also- extremely important issues of fisheries management, with specific sensitization discussion on local issues such as smuggling and misbehavior (use of illegal and/or harmful fishing techniques), resource stewardship, and potential obstacles to increase reservoir fishery production.

GENERAL DISCUSSION AND CONCLUSION

Ecological consideration on fishery reservoir productivity: lessons from CP34

The literature on reservoir ecology tells us that productivity in large reservoir ecosystems is intimately linked to the interplay between hydrology, nutrient dynamics and the fauna and flora which generate the services on which human communities depend for food and livelihoods.

Large reservoirs are ecosystems in transition from riverine to lacustrine. In particular, the two large dam reservoirs that were included in this project (Lake Volta and Lake Nasser) are about 50 years old and their fish populations remain in flux as species adapted to a riverine context evolve at both the biological and ecological levels into a more or less stable lake stock. Two major phenomena dominate this process: 1) relative competitiveness for altered food resources leading to the reduction or elimination of species that may once have been abundant and vice versa, and 2) the development of vacant ecological niches where no riverine species is able to take advantage of a new food resource. Most particular in this latter case are species such as the lacustrine pelagic clupeids, *Limnothrissa miodon* from Lake Tanganyika or *Rastrineobola argenteus* from Lake Victoria that can capture and digest newly generated abundance of phyto and zooplankton, which are normally rare in rivers.

In general terms the introduction of species that might take advantage of underutilized food resources is constrained by the dangers associated with the introduction of non-indigenous species. In cases where this has been done however, huge gains in productivity have often been achieved (e.g. Lake Kariba), but sometimes with dramatic loss of biodiversity (e.g. Lake Victoria)¹⁴. On the other hand, even in large reservoirs where exotic species introduction is not permitted –as it is the cases of Lakes Nasser and Volta–, feeding and fish stock enhancement through release of preferred species either managed in enclosures and cages, or released for later capture in the fishery may also yield productivity increases.

The context and background for the chosen methods to increase productivity are however largely based on the institutional context or perceptions about the system states and processes –and how one may influence them. Those perceptions –which may have, for their majority, their origin in scientific knowledge– have not however been necessarily systematically tested. Solutions to improving productivity in Indian reservoirs were for instance initially based on a view on mechanisms governing productivity while actual empirical evidence of these relations is scarce, and a more comprehensive view of productivity processes and fish communities is still needed. In Lake Nasser stocking of native fish (tilapia) has already been performed regularly since 1990 without prior examination of the natural recruitment potential of these species, and with no later empirical information or evaluation on the effect of stocking. In Lake Volta, adoption of the small-scale cage culture was considered as the only viable option due a mixture of perceived negative impact of the present exploitation pattern and the success of private aquaculture farms in the lake.

The inherent constraints of the institutional knowledge and tradition are illustrated by the achieved results. Although the implementation of methodologies was partly successful in some of the cases, it must be generally concluded that the overall success of the chosen approaches were limited. For the IGB case, there was found to be no clear relations between the ambient bio-physical indicators and the reservoirs production, and this suggests that exerted fishing effort is determined by other factors than reservoir productivity (van Zwieten et al. 2009). In accordance, the analysis (page 61) highlighted that “a great part of the factors which influence the success (and the failure) of the adoption and/or viability of technical innovations are related to social, economic and more broadly, institutional factors” pointing for instance to the leasing arrangements on reservoirs. For Lake Nasser, the enclosure experiment is yet inconclusive (partly due to poor monitoring), although similar previous private attempts in the lake have to a large extent been abandoned,

¹⁴ Importantly, the planktivorous *L. miodon* was introduced to Lake kariba, while the piscivorous *L. niloticus* was put into Lake Victoria.

which indicates limited success. For Volta Lake, the economically viable scale of small-cage aquaculture may be beyond the means of the really poor, but the catch assessment and the *acadja* study at least gave a much better understanding of the ongoing local exploitation pattern in the lake than was available prior to the project.

Overall the present study suggests that reservoirs in the Indo-Gangetic Basin were the most amenable to manipulation, being relatively small and under strict government control with local management.

A potential useful comparison that was largely untapped in the project would have been between the highly fluctuating lake Volta, with its enormous changes in lake surface area that in many ways make the lake resemble a floodplain and its associated highly adaptive multispecies-multigear fisheries, and the more lacustrine Lake Nasser with its basically single species targeting fisheries. Both lakes are deemed oligotrophic but have highly divergent fisheries production characteristics, causes of which could have been explored further to better understand productivity processes and potential improvements in them. Rivers and floodplains are much less open to classic fisheries controls and Lake Volta fisheries has all the characteristics of such fisheries: highly motile fisheries population, chosen appropriate gears and spaces throughout the flood-cycle; highly dispersed and temporal markets with large role for fish traders; production processes to a large extent driven by the environment. Lake Nasser fisheries, can in principle be organized more formally (though the present set-up with only a few markets and a requisition of collector boats to report a certain amount of fish may be too restrictive) as it resembles much more a stable system dominated by a few important species. The institutional context however precludes such an analysis because of the dominant fisheries management paradigm that fisheries effort drives fisheries production, and optimisation of inputs or outputs by regulating effort should take place.

Socio-institutional considerations on reservoir fishery productivity

A relatively rich literature is available that links existing reservoir productivity to a wide range of environmental factors. In contrast, very little has been proposed to include socio-institutional considerations into those discussions, despite the significant literature that emphasizes the importance of collective actions and social and/or economic factors in explaining activities related to the exploitation of natural resources and common pool resources.

The research presented in this report was a first attempt to address this flaw. Using the project primary data, we explored some new directions. The investigations were limited by the nature and quality of the information, but some instructive conclusions were achieved.

Let's first recall that institutions or policies may not always provide positive incentives for individual or collective behavior. They can also in certain circumstances create counterproductive environment which will, in the long-term, greatly limit the sound development of a specific economic activity. That is the case in particular in the Lake Nasser fishery where our research showed how the combination of inadequate policies and economic and management tools have led to the creation of a massive black market.

From the research, it also appears that the interventions which yield the highest returns on research and extension investment, as well as time and money contributed by local stakeholders tend to be out of reach of the poorest of the poor. Two reasons seem to predominate: 1) capital required for enclosure, cage or stock enhancement exceeds the spending power of the lower echelons of society and, 2) management skills and an orientation towards organized labor investment are generally lacking among the very poor.

Benefits accruing to the poor through the value chain of culture-based fisheries activities (e.g., employment opportunities, lower cost fish for home consumption) are possible, but were not documented in this study. For the poor to be directly involved at a level that has a chance of producing impacts on a scale with the levels of poverty prevailing in Egypt, Ghana and India will

Objectives CPWF Project Report

require substantial government and/or NGO involvement, which may take the form of subsidies in terms of capital and/or logistical and technical support. In the absence of such subsidies, development of the culture-based fisheries sub-sector will continue to be a haphazard affair with increased productivity resulting from the occasional happy coincidence of competent management combined with community support, sound technology and adequate capital.

In sum, manipulation of reservoir ecosystems to improve productivity and outcomes for lower income communities is feasible, but to be realized, adaptive research needs to work closely with technology users to ensure that the rationale of the intervention and the technical details are fully appreciated by local stakeholders and, maybe more importantly, that research and extension come to understand the real opportunities and constraints confronted by potential investors.

Overall, those different reflections highlight the necessity to continue to combine social, economic and policy analysis with the more conventional ecological and bio-physical approach if we are intended to improve our capacities to engage with, and support, local populations and governments in their attempt to improve the productivity of tropical reservoir fisheries.

Conclusion

The current project has been conceptualized, planned and managed to a large extent by social (science) concerns – as well as general CPWF requirements – resulting in a strong focus on engaging with communities to adopt and adapt technologies to improving productivity. A clearly positive effect of this focus is that it has forced institutions with a strong “natural science” background to go out and engage with local communities to find the gaps in knowledge and discuss the adaptation of the existing technologies to local circumstances. However, it is still by and large implicitly assumed that the local communities shall adjust more to the institutions than vice versa. We, as part of these institutions, are the providers, while they, the communities remain the recipients.

Community responses to increasing demands for fish are always resulting in local solutions to increase production and productivity on a constant trial and error basis. For instance, in Lake Nasser local experiments with enclosures were already tried and tested well before CP34 started, and increased production (unreported) was simply provided by an increase in effort (although unlicensed and technically illegal); cage culture is already being attempted in Lake Volta by various types of entrepreneurs with different (variable) results, and culture based fisheries, such as brush-parks (*acadja's*) have already a long history in West Africa. Likewise stocking of reservoirs in India has been deemed necessary and practiced for years. In that context, adapting institutional set-ups, frameworks and management to carefully understand and evaluate initiatives from the community will go a long way in facilitating these processes, instead of per default regarding any local adaptation or innovation as a potential recipe for disaster. The top-down “management belief”, often accompanied by a “technological fix belief” of most fisheries institutions is in many ways hampering the synergetic processes that should link practical bottom-up (local) ingenuity and entrepreneurship of the local communities with theoretical insights and comparative experiences developed elsewhere.

Overall, most of the chosen methodologies are relatively expensive and requires a far better control of the biological production processes than most natural reservoirs can offer (with the exception perhaps of the very small reservoirs). The technologies tested in India gave good and predictable results but these might only be marginal in the wider context. The larger question still remains: why productivity is so extremely low in Indian small reservoirs? Testing enclosures in Lake Nasser was perhaps one of the few options that actually could be done to attempt increasing productivity without deeper knowledge about natural productivity. But again the larger questions would be to know what the actual natural productivity of Lake Nasser is, what the main controlling factors of this productivity are, and what the status of the exploited stocks are in relation to the existing fishing pressure.

In other words, the achieved results are in many ways relatively marginal compared to the already developed fishing practices, largely adapted to the natural productivity of the different stocks, and their economic viability has yet to be proven. Again there seems to be a paradoxical discrepancy between the institutional theoretical –and mostly expensive- solution, and the local practical adaptations through trial and error. Where the institution believes it can govern, manage, enhance, manipulate and control the production processes, the local fishers follow, fluctuate, optimize and adapt to the given natural production processes. Often (as illustrated by the catch assessment study in Lake Volta) they have local knowledge about fish behavior, production and seasonal changes that largely outstrips the institutions that are supposed to regulate them, and they are able to increase production by a variety of methods. Unfortunately, as demands increases, many of the methods, such as a decrease in mesh sizes and an increase in the diversity of gears in order to utilize at all categorical, trophic, spatial and temporal levels, are often technically illegal, although the scientific rationale behind these regulations has rarely been studied. At the same time the institutions (as the case with Nasser and Volta) are not in a position to even monitor the resulting increased production from local activities, but instead become inherently worried about unsubstantiated overfishing threats. For both Lake Nasser and Lake Volta the official landing statistics are seriously underestimated, and for all the cases the actual natural potential, or factual status of the exploited stocks, is virtually unknown. Such limitations make the achieved (technical) results of the present project very difficult to evaluate objectively both quantitatively and economically.

The general problem, which is not unique to the present project, seems to be the fundamental different perceptions of the exploited system between the managing institutions and the performing practitioners.

OUTCOMES AND IMPACTS

Description of the Project's Main Impact Pathways

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
CIFRI				
Targeted state Department of Fisheries Official/officers				
Field level	i) Practice in collection of data on fish catch	Significance of recording data properly; Improved method in data collection. Technique of raising fingerlings in cages.	i) Involvement of stakeholders in project implementation ii) Capacity building of stakeholders	Sixty fishers and field level officials trained in better management practices.
Policy level	i) Fisheries enhancements iii) Establishment of self finance system	Importance of scientific management of reservoirs	iii) Demonstration of enhancement strategy	Demonstration at reservoir sites, lead to bring 30 more reservoirs under management by State Government
Fishers	i) Improved Transportation of produce ii) participation in self finance system	Understanding of negative impact of catching undersized fish	Involvement of stakeholders in project implementation activities.	Increment in fishers income by 32% One financing system established
Lessee	Shift in stocking practices	Understanding the impact of stocking of right kind of fish seed	Demonstration of enhancement strategy and practices.	Increment in fish production by one and half times
Concerned university supervisors	Practice of working in collaboration with development departments and national level institutes	Gain in knowledge about fisheries management	Generation of additional scientific information.	Datasets were generated. Five PhD Thesis
Project Investigators	Practice of working in participatory mode. In-situ fingerling production practice	Better understanding reservoir fishery management and new project monitoring techniques. Standardizing fingerling production skills in cages.	Organization of basin workshops & participation in inter-basin level workshops. Verification of enhancement tool	Lead to successful implementation of the project.

Outcomes and Impacts **CPWF Project Report**

NIOF-LNDA				
Scientific Team	data collection new techniques for data analysis Project management	Improving data collection New methods for data analysis Experience in publications	Publications Workshops	No possible quantification
Official authorities	Project management Relation with fisher and stakeholders	Experience in project management and administration Building good relation between official authorities and stakeholders	Participatory research through Scale out project advantages to stakeholders of new research results and its application to improve fish production from the lake Scale up the recommendation gained in the project to decision makers	No possible quantification
Primary stakeholders	Fishery knowledge Fish processing Fish transportation Enhance Fish Productivity	New ideas for fishery management Using of wood cabin for fish salting Using ice boxes for fish transportation to improve quality Fish enclosures to increase productivity from <i>khors</i>	Increasing the value of fresh fish through new transportation techniques (ice boxes) Reducing the amount of spoiled fish due to improved salting techniques (wood cabins) Improving fish production through stocking of fish fry in enclosures	No possible quantification
Fishery Cooperative societies	Confidence between cooperatives and official authorities	Knowledge, experience, And Information	Increasing Knowledge exchange regarding fishing regulations, net specification, license and investment return on fishers	No possible quantification
WRI				
Research Team	Apply participatory approaches in research activities	*Appreciating the fact that participatory approaches give more data; *Improve skills in participatory research activities i.e. e.g. appreciate engaging the community more seriously in the planning and implementation of research activities	Investment of time and financial resources in demonstrations * Intensive participatory research strategy Results of fish production by small scale-cage culture	Improved by 72%
Traditional Team	More active support in participatory research activities	More open and receptive to research collaboration (e.g. offer traditional support)	Potential of small-scale fish cage culture and improved fish smoking facilities as industries in their areas to provide employment and enhance food	Improved by 75%

Outcomes and Impacts CPWF Project Report

Local Government authority	More active support in participatory research activities	More open and receptive to research collaboration (e.g. offer political support)	security and livelihood. Potential of small-scale fish cage culture and improved fish smoking facilities as industries in their areas to provide employment and enhance food security and livelihood.	Improved by 80%
Primary Stakeholders Fishers Fishmongers Traders	<ul style="list-style-type: none"> ▪ Now engage in cage culture) ▪ More people now keep quality records with respect to catch, business, etc. ▪ Related Cage culture businesses (e.g. fingerlings and feed production, and cage manufacture) are now being undertaken; ▪ Fish smokers are now investing in more improved fish smoking oven technologies e.g. the FRI-Fish Smoker. ▪ Some NGOs are involved in construction of oven, development of fish development ovens. 	<p>Appreciated self-financing issue;</p> <p>Eagerness to adopt proven new technologies to improve their livelihood (e.g. income), social status, and well-being.</p>	<p>Better smoked fish from improved oven;</p> <p>Time gained, the comfort, and reduction of health hazards associated with the improved oven usage</p>	Improved by 75%
	Change in attitude in the practice of Brush Park Atidza/ Acadjas	Change in practice: (i) consideration of Atidza/acadja practice as a scientifically valid fish production and fisheries management approach; (ii)	This was due to sharing of scientific information on Brush Parks functioning with fishers.	

Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?

CIFRI - Low cost in-situ production of fingerling through cage units; Bicycle mounted icebox for fish transport. Both interventions improved fish productivity and in turn benefited fisher community / lessee.

NIOF-LNDA - The idea of establishing fish enclosures in selected and ecologically suitable sites seems to be the most expected idea for stakeholders to increase fish production. With a huge area in the lake that can be converted to fish enclosures, the beneficiary effect could be huge in increasing fish production from the lake.

WRI - The changes with greatest potential to be adopted include:

- intensive participatory research in bio-physical, fish catch and stock assessments - by researchers;
- promotion of small scale cage culture - by researchers, primary fisheries stakeholders and entrepreneurs;
- improved fish smoking oven - by fish processors, entrepreneurs and development partners;
- fisheries record-keeping by the primary stakeholders (fishers, fish processors and traders).

The potential on the ultimate beneficiaries include:

- Adoption of intensive participatory research approach: (i) in research planning, implementation and output; (ii) enhancing community insight and appreciation of research benefits; (iii) enhancing traditional and local authority attitude and recognition.
- Adoption of small-scale fish cage culture has the potential of: (i) employment generation, (ii) food security, (iii) recognising and having better understanding of the economics of fish cage culture.
- Adoption improved fish smoking oven has the potential of: (i) enhancing income of fish smokers and traders through presentation of improved quality fish on the market; (ii) reducing health risks associated

- with fish smoking; (iii) making time available for fish smokers for other productive activities
- Adoption of improved fisheries record-keeping has the potential of: (i) fishers, fish processors and traders having better appreciation of their business; (ii) contributing to research data collection, and reduction in time and cost of research;

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.

CIFRI - The results of the project should be scaled out at different reservoir sites in these two states. The concerned stakeholders are convinced about the outputs of the project are expected to follow it up with their own resources.

NIOF-LNDA – Although the data collected through this project were not satisfactory to evaluate the process of enclosures due to shortage of time, we still have commitment to complete the experiment of this project and improve data collection from enclosures. It is necessary also to repeat the enclosure experiment at different localities and using the experience gained during this project. It is preferable to submit an extended project for at least two years to use the present infrastructure, information, and experience to reevaluate the economic return and new techniques in management of enclosures.

WRI - To achieve the potential of improving research planning, implementation and output through adoption of intensive participatory research approach:

- Requires dissemination of the approach through workshops, seminars, conferences, manuals and scientific publications.
- Currently there are no measures in place for dissemination of the approach.
- At the end of project, proposal on the issue would be developed to seek funding;

To achieve the potentials of small-scale fish cage culture and those of the improved fish smoking oven, development agencies would have to consider up-scaling outputs of current project (i.e. CP. 34). Already the Ministry of Food and Agriculture through the Directorate of Fisheries in Ghana is implementing an aquaculture input support (on credit) to fish farmers including small-scale fish cage farmers. Also, a pilot micro-credit scheme is in place to provide inputs (cages, feed, fingerlings, training, and technical support) to potential small-scale fish cage culture farmers. An NGO has also taken up credit scheme to provide the improved oven.

After the project, proposal would be developed for other development partners consideration to further upscale small-scale fish cage culture.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors.

Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)

CIFRI

- Achieved highest growth (9 times) and survival (86%) in cage reared fingerlings of major carps. It was not envisaged at the initiation of experiment and lead to more fingerling production for stocking.
- In spite of *Microsystis* dominance in Pahunj reservoir the growth performance of major carps especially of *Catla catla* was significantly higher in terms of growth, which was not anticipated. Contributing to production increase.
- The fishery enhancement strategies achieved higher production in comparison to previously envisaged at the start of project.
- The success achieved in bio-manipulation of stocks through external stocking provided the fisher community/lessee with more quantity of high values species resulting in better returns for his catch. The significant shift to the tune of 50% in favor of major carps was not anticipated to be achieved during project period.
- High level of acceptance of scientific management of reservoir fishery model developed through this project by the Madhya state fishery authorities.

NIOF-LNDA

Up to now, fish catch transported from fishing grounds to landing sites were transported using one single box (container) inside the carrier boat, and filled with mixed sizes and species in random conditions putting ice over it. Fish transported by this method were in deformed shape and in bad quality.

We planned to use ice boxes to transfer fresh fish in good condition from enclosures to landing site, then to the whole sale market in Cairo. Implementation of this pathway resulted in some difficulties related to high temperatures in summer. Ice melted due to high temperature in summer affects the shape and quality of fish transferred by this method. But in winter, fish transported using this technique had good benefits for producers reflected in high marketing price (~ L.E. 2.0 -2.5).

Outcomes and Impacts **CPWF Project Report**

WRI

- The involvement and commitment of fishers in catch data collection were above expectation.
- With respect to quality of data and therefore contributed to research output.
- The project did not anticipate the level of commitments of the fishers because (i) the fishers had to combine their usual fishing and other livelihood activities with the project assignments.
- The involvement and commitment of fishers in catch data collection enabled the research team to save time, and got more and quality data.
- Low uptake/involvement of fishers in small-scale fish cage culture compared to non-fishers.

Why were they unexpected? How was the project able to take advantage of them?

NIOF-LNDA

- It is the first time to use this technique for fish transportation in Lake Nasser, and melted ice was not expected to cause this problem. The project advised carrier boat owners to use a new method for fish transport. Size and species grading is proposed at the fishing site, then fish is transported by carrier boats with ice to the landing site. Trucks (refrigerated or using ice) are used to transport fish from landing site to whole sale market.

WRI

The low uptake of fishers in small-scale fish cage culture compared to non-fishers might be due to the inability of the former to raise the necessary capital to invest in this technology. The project encouraged entrepreneurs to engage fishers in their operation of small-scale fish cage culture so as to build capacities of fishers to be able to establish their own in the future.

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?

CIFRI

- Refine and upscale the data collection approach for bio-physical, fishery, social structure and enhancement technologies in reservoir located in varied agro-ecological situations.
- Based on the knowledge gained provide additional inputs to policy makers for harnessing potential technology of increasing productivity.
- Conduct more demonstration programmes and identify one site for continued training for developing of adequate trained manpower in reservoir fishery management.

NIOF-LNDA

We would encourage the attitude of more carrier boat owners, fishers and fish traders to use this technique. This could be done by increasing awareness and knowledge among these people about the advantages and benefits of this method.

WRI –

- Limit the range of activities of the project to enable greater involvement of the primary stakeholders in order to achieve better results/outputs.
- Broaden the range of target group for training in small-scale fish cage culture to include fishers and small-scale entrepreneurs;
- Would have requested more resources to undertake more demonstration
- Would have organised training of trainers programmes for the trainers to facilitate changes in knowledge, attitude, skills and practice in the activities of the project.

International Public Goods

New Insights

By developing and testing a combination of carefully adapted stock enhancements and aquaculture activities in three different basin and four different sized reservoirs, the project provides an interesting overall insight into the current research on reservoirs enhancement fisheries in tropical countries. Beyond the areas of intervention of the project, those researches offer useful lessons for practitioners and/or researchers interested in similar activities in the same basins or elsewhere in the tropical region. A large part of those lessons concerns technical aspects (see 'tool and methodology' in this IPG section below) but some wider reflections on the general issue of water productivity in small and larger reservoirs were also discussed. Those reflections have been initiated through three individual basin reviews (CIFRI 2005, NIOF-LNDA 2005, WRI 2006), a

global synthesis document (van Zwieten et al., 2009) and a specific report on water productivity in fisheries (Lemoalle 2009). Additional works were published on specific bio-physical or fisheries characteristics of some of the reservoirs (e.g. Abd Ellah 2008, El Haweet et al. 2008, Karikari *et al.* submitted).

Another critical area where the project offers relevant insights for which very little is usually found in the literature is the socio-institutional and economic processes associated with those fisheries enhancement activities. Through various analyses and different angles the project investigated several of these socio-institutional processes, including the role of leasing rights on reservoirs productivity, the effect of contractual arrangements on fisher incentives and capacity to engage in the fishery, and the potential issues related to the 'privatization of the commons' usually associated with investments in enhancing techniques (cage, stocking, etc.). A series of publications that describe and analyze those different issues has been submitted to various peer-reviewed journals (Béné e al. 2008, Béné and Obirih-Opareh –in revision, Finegold et al. submitted, Katiha et al. submitted).

Tools and methodology

The main effort of the project has been on developing and testing appropriate tools and methodologies to increase productivity of fisheries in lakes and reservoirs: enclosures in Lake Nasser embayments (*khors*), pens and cages to raise fry for stocking Indian reservoirs, and small-scale cage culture in Lake Volta. The main results of those trials were documented in a series of articles submitted to peer-reviewed journals (Ofori et al. in press, Das et al submitted). A series of Technical Manual produced by the project summarizes the practicalities of applying those methods in the three basins (CIFRI-CP34 2008, 2009, LNDA-CP34 2009, WorldFish-CP34 2009, WRI-CP34 2009).

In addition a number of fish processing/conservation techniques have been developed or tested: the SRI fish smoking oven in Lake Volta, wood chamber for fish salting in Lake Nasser, and ice boxes for fish transportation in India. Those represent as many options that can adopted in other part of the world.

Datasets

The following series of data have been generated:

Type of data	Succinct description	Format	Contact
Bio-physical data			
	Lake Volta: Bio-chemical water quality data from since similar data in the 1969/1970	Excel	Mr. Hederick R. Dankwa CSIR-Water Research Institute P. O. Box M32 Accra, Ghana e-mail: hr_dankwa@yahoo.com
	Lake Nasser: (seasonal) in and out enclosures, and fish experimental catch in enclosures	Excel	Prof Soliman National Institute of Oceanography & Fisheries Qayet Bay, Anfoushy, Alexandria City, Egypt e-mail: soliman_a@yahoo.com
	Indo-Gangetic Basin: dataset of 642 small and medium reservoirs, including bio-physical, stocking data, production, general socio-institutional background (distance to markets, number of fishers)	Excel	Director, CIFRI, Barrackpore, Kolkata – 700120 West Bengal, India e-mail: cifri@vsnl.com
	Jahod and Pahuji reservoirs: complete limnological information from Sept. 2006 to April 2009 (chemistry, plankton, fish catch)	Excel	Director, CIFRI, Barrackpore, Kolkata - 700120 West Bengal, India e-mail: cifri@vsnl.com
Fisheries data			

Outcomes and Impacts CPWF Project Report

	Lake Volta: catch assessment data: Period- March 2007-June 2008 No. of Data =50794 records Nature Length/wt data	pasgear	Mr. Hederick R. Dankwa CSIR-Water Research Institute P. O. Box M32 Accra, Ghana e-mail: hr_dankwa@yahoo.com
Socio-economics			
	Lake Volta: socio-economic baseline data: 182 fishing household data including household assets index, fishing assets, perception and socio-economics of <i>acadjas</i>)	Excel	Dr. Nelson Obirih-Opareh, Head of Division, Agriculture, Medicine and Environment Division, STEPRI. P.O. Box CT. 519, Cantonment, Accra, Ghana, e-mail: nobirih_opareh@yahoo.com or Chris Béné Policy, Economics and Social Science, The WorldFish Center P.O. Box 500, GPO, 10670 Penang, Malaysia e-mail: c.bene@cgiar.org
	Lake Nasser: socio-economic baseline data: 125 fisher interview data (fishing strategies, socio-economic background, individual catch estimate, contractual arrangement)	Excel	M. Shehata Lake Nasser Development Authority, P.O. Box 129 Aswan, Egypt shehata.khalifa@yahoo.com or Chris Béné Policy, Economics and Social Science, The WorldFish Center P.O. Box 500, GPO, 10670 Penang, Malaysia e-mail: c.bene@cgiar.org
	Jahod and Pahuj reservoirs: Dataset on socio-economics of fishers, including demographic pattern; level of literacy, employment and income; domestic assets; fisheries requisites; fishing practices followed; fisheries activities, effort and fish catch	Excel	Director, CIFRI, Barrackpore, Kolkata - 700120 West Bengal, INDIA e-mail: cifri@vsnl.com
	Indo-Gangetic Basin: Dataset for fish market prices in Uttar Pradesh and Madhya Pradesh	Excel	Director, CIFRI, Barrackpore, Kolkata - 700120 West Bengal, INDIA e-mail: cifri@vsnl.com
Cage culture			
	Lake Volta: fish cage experiment data (water quality, fish growth and cage economics)	Excel	Dr. E.K. Abban CSIR-Water Research Institute P. O. Box M32 Accra, Ghana e-mail: kofi_abban@yahoo.co.uk
	Jahod and Pahuj reservoirs: Data on fry culture, stocking, and economics of cage culture for fish seed raising	Excel	Director, CIFRI, Barrackpore, Kolkata - 700120 West Bengal, INDIA e-mail: cifri@vsnl.com

For each of these datasets, a proforma and/or questionnaires have been developed.

Publications

See section publication below

Partnership Achievements

NIOF-LNDA

1- Partnership achievements in science:

- Scientific cooperation and exchange of ideas, project management procedures, scientific publications, workshops with WorldFish Center.
- Ph.D. program to study Bio-socio-economics of Lake Nasser Fisheries between LNDA and Tanta University.
- Ph.D. program to study zooplankton and epiphytic zooplankton in Lake Nasser.
- Scientific cooperation between LNDA and NIOF in studying biophysical conditions and fisheries in Lake Nasser.
- Scientific cooperation with South Valley University in studying the macrophyte distribution in Lake Nasser.

2- Partnership achievements in outcomes:

- Cooperation with enclosure owners to apply new methods for fish transportation.
- Cooperation with fisher to improve salting procedures of fish and apply new techniques using hygienic methods inside wooden cabins.
- Applying locally new system for fish culture inside enclosures in Lake Nasser adapting economic practices.

3- Partnership achievements in impacts:

- Scale out project advantages stakeholders of new research results and its application to improve fish production from the lake
- Scale up the recommendation gained in the project to decision makers

CIFRI

1- Partnership achievements in science

- The partnerships with Bundelkhand, Barkatullah and Vidysagar Universities resulted in generation of additional data set for ecology and fisheries of reservoirs and socio-economics of fishers.

2- Partnership achievements in outcomes:

- The partnerships with Department of Fisheries Governments of Madhya Pradesh and Uttar Pradesh helped in successful conduct of project experiments and its implementation.
- The co-operation extended by The Ministry of Agriculture, Government of India and Department of Fisheries in IG Basin states helped in compilation of inventory report.

3- Partnership achievements in impacts:

- The partnership with World Fish Centre led to identification of socio-institutional factors influencing the fish productivity in tropical reservoir

WRI

The project necessitated partnership between different scientific institutions and fields within the NARES of Ghana (e.g. Aquatic Resources Research Institutions and social science policy. It also necessitated scientific partnership among different subject scientists:

- Partnership between scientists and fisherfolks community and sectors of the communities.
- Partnership with NGOs (e.g. Ghana Association of Women Entrepreneurs (GAWE), and Rural Wealth))

1- Partnership achievements in science

- Partnership between different subject scientists enhanced multidisciplinary approach to different issues of project and decision making;

2- Partnership achievements in outcomes:

- Partnership between scientists and primary stakeholders harmonised strict scientific approaches and real human needs modifications. The partnership also increased incorporation of scientific attitude and approaches of primary stakeholders in their activities. Finally, this partnership enhanced traditional knowledge of the scientists in the fisheries activities of primary stakeholders which could improve on interpretation of results.

3- Partnership achievements in impacts:

- Partnership between projects and NGOs enabled the application of business principles to the activities of the primary stakeholders.

Recommendations

- Given the general lack of understanding of biological production processes in larger (but also to some lower extent, smaller) reservoirs, there is still a need for further fundamental research on those processes.
- It is possible to manipulate, govern, and determine a natural environment, but vast opportunities still exist for increases in productivity from a purely biological point of view. The level of intensive methods should therefore be seen in relation to the spatial scale of the reservoir.
- The environmental sustainability of yield enhancement technology, especially the introduction of potentially eutrophying feeds and stocking of fish which do not naturally recruit into reservoir will depend to a large extent on the intensity and density of cages or enclosures and the invasiveness of introduced species. These impacts are easier to manage in smaller reservoirs. Larger bodies of water seem inherently less amenable to management.
- There is a need for carefully document and understand the natural production processes and their controls and limitations before endeavouring into technological solutions that may turn out to be economically or technically unaffordable for the poorest.
- The historical context and inherent scientific preconceptions that characterize research and management institutions should be acknowledged when evaluating the chosen pathways or ideas in the attempt to increase reservoir fishery productivity. Still, they should also be evaluated in a larger framework within currently available scientific knowledge and practices in order to classify these choices and help in understanding the distinction between theory and knowledge (separate beliefs and facts). In developing international programs as the current Challenge Programme, time and space should be made available to enable such evaluations.
- A close engagement with the local communities to identify the ongoing activities and developments, and gaps in the institutional knowledge, as well as a willingness to objectively test without prejudice their various adaptations seems at present to be much more rewarding in terms of increased productivity than technological solutions that require close control over all links in the chain.
- Given the importance of the socio-institutional and policy processes in influencing the overall capacities of local actors to engage/invest in technical innovation, further research and analysis of those processes is critical if one wishes to ensure a better contribution of research to the question of the productivity of reservoir fisheries.
- To increase their potential impacts, improved fish productivity projects in tropical countries should, as much as possible, include interventions that aim at increasing the capacity of fisherfolk communities in low-cost technologies and post harvest losses.
- Technological approaches to increasing productivity may have only *indirect* positive impacts on the poorest of the poor. Government logistical and technical support can increase the benefits accruing to lower income groups the overall cost of private investment in these technologies limits direct participation to less poor groups.
- Conflicts seem nearly inevitable in any system where benefits from the exploitation of common resources appear to accrue disproportionately to one group among several. Consultation and participation with local institutions and stakeholders can reduce these conflicts, but in situations of extreme poverty and heavy dependence upon natural resource exploitation for livelihoods, the extent to which privately-owned investments in common pool resources can contribute simultaneously to increased productivity *and* poverty reduction is therefore limited.

Publications

Peer-reviewed Journals

- Abd Ellah R.G. 2008. Physical Limnology of two enclosures in Lake Nasser, Egypt. *Egyptian Journal of Aquatic Research* 34(4): 247-259
- Béné C., Bandi B. and Durville F. 2008, Liberalization reform, 'neo-centralism' and black market: insight into the political economy of Lake Nasser fishery development. *Water Alternative* 1(2): 219-235.
- Béné C. and Obirih-Opareh N., Social and economic impacts of agricultural productivity intensification: the case of brush park fisheries in Lake Volta. *Agricultural Systems* (in press).
- Finegold C., Béné C. Shehata M., Habib, O.A. 2009. Productivity, capital mobilization and moral hazard in fishery: investigating their links through share contract theory in Lake Nasser (submitted)
- El Haweet A., El Hussein A., Sangq Y., and Elfar A. 2008. Assessment of Lake Nasser Fisheries. *Egyptian Journal of Aquatic Research* 34(2): 285-298
- Ofori J.K., Abban E.K., Karikari A.Y. Brummett R.E. Production economics of small-scale tilapia cage aquaculture in the Volta Lake, Ghana. *Journal of Applied Aquaculture* (in press)

Conference Proceedings

- Anubha Saxena, Mahesh Chauhan, Salim Sultan, V. I. Sharma and Pradeep K. Katiha. 2007. Retrospect and prospects of fisheries development in Bundelkhand region of Uttar Pradesh, Presented at "Ecosystem health and fish for tomorrow" at CIFRI, Barrackpore December 14-16, 2007, p.73
- Arya, S. L., and Khan, M. I. 2007, Pahunj Jalashaya kay Velanchal aevam Anupeey Chetr mai air Breething Machliyo kay Samvardhan ke sambhavnaye, Presented at. In Matsyaki Anusandhan Avam Vikas: Dishayen Aur Ayaam, Inland Fisheries Society of India and Central Inland Fisheries Research Institute, Barrackpore March 17-18, 2007 p. 32
- Arya, S.L., Srivastava, N.P., Das, A.K and Khan, M.I. 2007. Plankton Abundance in Relation to Macrophytes vis a vis Limno- Chemistry in a Small Reservoir in Jhansi, Uttar Pradesh, Presented at "Ecosystem health and fish for tomorrow" at CIFRI, Barrackpore December 14-16, 2007 p.28
- Arya, S. L., Vass, K. K., Shrivastava, N.P. , Das, A. K. and Khan, M. I. 2008. Spatio-temporal distribution of plankton in relation to limno-chemical features in a tropical reservoir of Uttar Pradesh, India, Presented at 8th Indian Fisheries Forum at Kolkata November 22-26, 2008 organised by IFSI, CIFRI and AFS. P.13
- Bara, S.K., Das, A.K. and Vass, K.K. 2007. Limno- Chemical Characterization of a Tropical Reservoir in Madhya Pradesh, India in the Context of its Fish Production Potential, Presented at "Ecosystem health and fish for tomorrow" at CIFRI, Barrackpore December 14-16, 2007 p.8
- Banik, S. K., Das, A. K., and Vass, K. K. 2008. Role of macrophytes in a small reservoir of Uttar Pradesh, India, Presented at. 8th Indian Fisheries Forum at Kolkata November 22-26, 2008 organised by IFSI, CIFRI and AFS. p-18
- Bara, S. K., Das, A. K., and Vass, K. K. 2008. Limno-chemical characterization of a central Indian reservoir, Dahod (Madhya Pradesh) – a decadal perspective, Presented at 8th Indian Fisheries Forum at Kolkata November 22-26, 2008 organised by IFSI, CIFRI and AFS, p.40
- Biswas, N.K., Vass, K.K., Srivastava, N.P and Das, A.K. 2007. Faunistic Diversity of Macro- Zoo benthos in Dahod Reservoir, Madhya Pradesh, India, Presented at "Ecosystem health and fish for tomorrow" at CIFRI, Barrackpore December 14-16, 2007, p. 28
- Das, A.K., Srivastava, N.P., Vass, K.K. and Arya, S.L. 2007. Weed Fishes in Small Reservoirs of India A bane or Boon, Presented at "Ecosystem health and fish for tomorrow" at CIFRI, Barrackpore December 14-16, 2007, p. 27
- Habib, O.A. and Béné C. 2008, Insights into the political dis-economy of Lake Nasser fishery Development. Paper presented at the IIFET 2008 Conference, July 22-25, Nha Trang, Vietnam

Outcomes and Impacts CPWF Project Report

- Habib, O.A. Improved fisheries productivity and management in tropical reservoirs. Poster presented at the 8th International Symposium on Tilapia in Aquaculture, 12-14 October, Cairo, Egypt
- Katiha, P. K., Béné, C. and Vass, K. K. 2008. Impact of socio-institutional factors on water productivity: Examples from the Indo-Gangetic Basin, Accepted for poster presentation at the IIFET 2008 Conference, July 22-25, Nha Trang, Vietnam
- Katiha, Pradeep K., Vass, K. K., Shrivastava, N. P., Sharma, V. K. and Sarkar, S. 2007. Inventory of Reservoirs in Indian Indo-Gangetic Basin for Fishery Enhancements, Presented at 12th World Lake Conference 28 October- 3 November 2007 p.226
- Katiha, Pradeep K., Bandopadhyay, M. K. and Biswas, D. K. 2007. Fisheries in Floodplain Wetlands of Eastern India: A Socio-economic and Institutional Perspective, Presented at 12th World Lake Conference at Jaipur 28 October- 3 November 2007, p.104.
- Katiha, P. K., Pal, M. K., Sarkar, S., Saxena, A. and Ghosh, S. 2008. Fish marketing efficiency and integration in Uttar Pradesh: A case study for reservoir fisheries, Presented at 8th Indian Fisheries Forum at Kolkata November 22-26, 2008 organised by IFSI, CIFRI and AFS. P.191
- Katiha, P. K., Vass, K. K., Sharma, V. K., Shrivastava, N. P. and Sarkar, S. 2007, Socio-Institutional Aspects Effecting Reservoir Fisheries in Rajasthan, Presented at VIII Asian Fisheries Forum at Kochi November, 20 to 23, 2007 p.404
- Katiha, P. K., Vass, K. K., Sharma, V.K. and Srivastava, N.P. 2007, Bhartiye Indus Ganga Basin kay Jalasayo ke Matsyaki mai Barotri avem Utpadkta mai Sudhar hetu Sansthatgat Vyavastha, Presented at Matsyaki Anusandhan Avam Vikas: Dishayen Aur Ayaam, Inland Fisheries Society of India and Central Inland Fisheries Research Institute, Barrackpore March 17-18, 2007 p.22
- Sanchita Sarkar, K. K. Vass, Anubha Saxena, Salim Sultan, Mahesh Chauhan, N. P. Shrivastava and Pradeep K. Katiha. 2007. Fisheries enhancements for reservoir fisheries development: Socio-economic and Institutional perspective, Presented at "Ecosystem health and fish for tomorrow" at CIFRI, Barrackpore December 14-16, 2007 p.73
- Sarkar, S., Saxena, A., Pal, M. K., Sultan, Salim, Gaur, R. K. Chauhan, M., Katiha, Pradeep K. 2008. Implications of reservoir leasing systems on fisheries: A case study in Uttar Pradesh, Presented at. 8th Indian Fisheries Forum at Kolkata November 22-26, 2008 organised by IFSI,CIFRI and AFS, p.165
- Saxena, A., Sarkar, S., Shrivastava, N. P. and Katiha, P. K. 2007, Matsyaki Vikas Ki Samsyayen Avam Samadhan , Presented at Matsyaki Anusandhan Avam Vikas: Dishayen Aur Ayaam, Inland Fisheries Society of India and Central Inland Fisheries Research Institute, Barrackpore March 17-18, 2007 p.30
- Saxena,A., Sarkar,S., Srivastava,N.P., and Katiha, P. K. 2007, Pahunj Jalashaya Mein Matsyaki Vikas Ki Samasyaen avam Sambhavnayen, Presented at Matsyaki Anusandhan Avam Vikas: Dishayen Aur Ayaam, Inland Fisheries Society of India and Central Inland Fisheries Research Institute, Barrackpore March 17-18, 2007, p.31
- Sharma, A., Das, A.K. and Lagarkha, R. 2007 Pahunj Jalasaye mai Jaleye Gurvatta Parivartan ka Machli Utpadan par Prabhav, Presented at Matsyaki Anusandhan Avam Vikas: Dishayen Aur Ayaam, Inland Fisheries Society of India and Central Inland Fisheries Research Institute, Barrackpore March 17-18, 2007, p.33
- Shrivastava, N. P., Singh, C., Saxena, A. Sarkar, S. and Katiha, P. K. 2007. Dahod Jalashaya Mein Matsyaki Vikas Ki Sambhavnayen, Presented at Matsyaki Anusandhan Avam Vikas: Dishayen Aur Ayaam, Inland Fisheries Society of India and Central Inland Fisheries Research Institute, Barrackpore March 17-18, 2007, p.30
- Sultan, Salim, Saxena, A., Gaur, R. K., Chauhan, M., Sarkar, S., Katiha Pradeep K. 2008. The dynamics of fish yield and revenue generation in different sized reservoirs of Bundelkhand region of Uttar Pradesh, Presented at 8th Indian Fisheries Forum at Kolkata November 22-26, 2008 organised by IFSI,CIFRI and AFS. p.198
- Tilak Singh Kushwaha, Pradeep K. Katiha, Anubha Saxena and N. P. Shrivastava. 2007. Knowledge on and training needs for reservoir fisheries: A case study of fishers in Madhya Pradesh, Presented at "Ecosystem health and fish for tomorrow" at CIFRI, Barrackpore December 14-16, 2007 p.71

- Vass, K. K. Pradeep K. Katiha, K. D. Joshi, Anubha Saxena, Tilak Singh Kushwaha and Sanchita Sarkar. 2007. Fisheries perspectives of Ken- Betwa Link Project (KBLP). Presented at Symposium on "Ecosystem health and fish for tomorrow" at CIFRI, Barrackpore December 14-16, 2007 p.74
- Vass, K. K., Katiha, P. K., Shrivastava, N. P., Sharma, V. K. and Das, A. K. 2007. Enhancement interventions and institutional arrangements to improve productivity of Indian reservoirs. Presented at VI IWMI-TATA Annual Partners' Meet, March 8-10, 2007 at IRM, Anand. p.23

Research papers

- Katiha, P.K., Vass, K.K., Sarkar, S. Saxena, A. 2009. Improving fish productivity and equity in common property waters: a study of Indian reservoirs under different fishing regimes, Central Inland Fisheries Research Institute, Barrackpore, India.
- Katiha, P. K., Béné, C. and Vass, K. K. 2009. Impact of socio-institutional factors on water productivity: Examples from the Indo-Gangetic Basin, Central Inland Fisheries Research Institute, Barrackpore, India.
- Dankwa, H. R., Agyakwah, S., Agbogah, K., Abban, E. K. and Kolding, J. 2009 Review of catch trends and changes in fish species composition of the Volta Lake during its 45 years of existence. Water Research Institute, Achimota, Ghana

Technical Manuals

- CIFRI-CP34, 2008. Cage Culture in Indian reservoirs. Technical manual prepared for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food, Central Inland Fisheries Research Institute, Barrackpore, India, 23 p.
- CIFRI-CP34, 2009. Enhancing fishery productivity in small reservoir in India. Technical manual prepared for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food, Central Inland Fisheries Research Institute, Barrackpore, India.
- LNDA-CP34, 2009, Building enclosure in Lake Nasser. Technical manual prepared for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food, Lake Nasser Development Authority, Egypt.
- WorldFish-CP34, 2009. Engaging local communities in aquatic resources research. Technical manual prepared for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food, WorldFish Center Penang, Malaysia.
- WRI-CP34, 2009. Producing Tilapia in small cage in West Africa. Technical manual prepared for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food, Water Research Institute, Achimota, Ghana.

Ph.D Thesis or dissertation

- Agyakwah S.K. (on-going) Fish Catch and stock assessment in Tropical Reservoir Towards Improved Fisheries: A case study in a segment of the Volta Lake-Ghana Ph.D. Thesis, University of Ghana, Legon
- Arya, Shyam Lal. (on-going) Plankton dynamics in relation to fisheries productivity in Pahuj reservoir, Uttar Pradesh., Ph.D. Thesis, Bundelkhand University, Jhansi, Uttar Pradesh
- Banik, S. K. (on-going) Investigation of morpho-limno-chemical features in relation to fish productivity of Pahuj reservoir, Uttar Pradesh, India. Ph.D. Thesis, Department of Chemistry, Bundelkhand University, Jhansi
- Bara, Satish Kumar. (on-going) Fish production potential of a Tropical Water body (Dahod reservoir) vis-a-vis energy dynamics. Ph.D. Thesis, Barkatullah University, Bhopal

Outcomes and Impacts **CPWF Project Report**

- Biswas, Nirmal. (on-going) Fish productivity of a Tropical water body (Dahod reservoir) in relation to plankton. Ph.D. Thesis, Barkatullah University, Bhopal
- El Sayed H.R. (on-going) Ecological studies on planktonic and epiphytic microinvertebrates in Lake Nasser, Egypt. Faculty of Science, Benha University, Egypt
- Sarkar, Sanchita. (on-going) Reservoir Fisheries Development in Indian Indo-Gangetic Basin: An Econo-institutional Perspective. Ph, D. Thesis, Vidyasagar University, Midnapore, West Bengal
- Shehata, M. (on-going) Studies on Bio-socio-economics of High Dam Lake fishers, PhD diss., Zoology department, Faculty of Science, Tanta University, Egypt.

Project reports

- CIFRI 2005 Desk based Review for the Indo-Gangetic Basin. Final report for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food, Central Inland Fisheries Research Institute, Barrackpore, 55p.
- Lemoalle, J. 2008. Water productivity of aquatic systems. Final report for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food and the WorldFish Center, Penang, Malaysia, 32 p. http://www.worldfishcenter.org/resource_centre/WPfisheries_final_report.pdf
- NIOF-LNDA 2005 Inventory and background analysis of the Lake Nasser. Final report for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food, The National Institute of Oceanography and Fisheries and Lake Nasser Development Authority, Alexandria and Aswan, 128 p.
- P.A.M. van Zwieten, C. Béné, J. Kolding, and R. Brummett (editors), 2008. Review of tropical reservoirs and their fisheries in developing countries: the cases of the Lake Nasser, Lake Volta and Indo-Gangetic basin reservoirs (with the contributions of E.K. Abban, H. Adam, K. Agboga, H.R. Dankwa, O. Habib, P. Katiha, I. Omar, M. Shehata, S.H. Abdel-Rahman, K.K. Vass, M. Zaki) Final report for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food and the WorldFish Center, Penang, Malaysia, 133 p.
- WRI, 2006. Review of the Lake Volta fisheries. Final report for the Project: Improved fisheries productivity and management in tropical reservoirs, CP-PN34: Challenge Program on Water and Food, The Water Research Institute, Achimota, Ghana, 47 p.

BIBLIOGRAPHY

- Abban, E.K. (1999). Integrated development of artisanal fisheries. IDAF Project GHA/93/008
- Abdel-Azim, M.E. 1974. Biological studies on *Tilapia nilotica* L. and *Tilapia galilae* in Lake Nasser. M.Sc. Thesis, Alexandria. Univ., Egypt.
- Abdel-Azim, M.E. 1982. Biological Studies on Some - Cyprinids from Lake Nasser. Unpublished Ph.D Thesis, Alexandria University, Alexandria, Egypt.
- Adam El. A. 2004. Stock assessment of some important commercial fish species of lake Nasser, Egypt. Ph.D. Thesis, Faculty of Science, Assiut University, 396 p.
- Ahmad, I., Bland, S. R., Price, C. R. and Kershaw, R. 1998. Open water stocking in Bangladesh: experiences from the third fisheries project. In Petr T. (Ed.), Inland fishery enhancements. FAO Fisheries Technical Paper 374, Rome: Food and Agriculture Organization and UK Department for International Development. pp.337-350
- Ahmed U.K. 1998. The population dynamics of *Oreochromis niloticus* and *Sarotherodon galilaeus* from Lake Nasser. ICLARM Symposium on Ecological Basis and Management Policy for Sustainable Fish Production in Lake Nasser, High Dam Lake Development Authority, June 20-23 Aswan, Egypt.
- Ali, L. and Islam, M. Z. 1998. An assessment of the economic benefit from stocking seasonal floodplains in Bangladesh. pp.289-308. In Petr T. (Ed.), Inland fishery enhancements. FAO Fisheries Technical Paper 374, Rome: Food and Agriculture Organization and UK Department for International Development.
- American Public Health Association (APHA) 1995. Standard Methods for the Examination of Water and Wastewater. AWWA, WPCF, 1015 pp.
- APHA-AWWA-WEF. 1998. Standard methods for the examination of water and wastewater, 20th Edition, American Public Health Association, Washington, DC
- Antwi, L.A.K. 1990. Limno-chemistry of Volta Lake 25 years after its formation. Institute of Aquatic Biology, Tech. Report. 11p
- Apu, N. A. and Middendrop, H. A. J. 1998. Establishing fishers groups for self-management of enhanced fisheries in semi-closed waterbodies in Western Bangladesh (the experience of the Oxbow Lakes small scale fishermen project). In Petr T. (Ed.), Inland fishery enhancements. FAO Fisheries Technical Paper 374, Rome: Food and Agriculture Organization and UK Department for International Development. pp.393-406
- Asante, F.A. 2006. Socio-economics of fisheries dependant communities in the Volta Basin of Ghana. International Journal of Ecology and Environmental Sciences 32(1):127-132.
- Balarin, J.D. and R.D. Haller. 1982. The intensive culture of tilapia in tanks, raceways and cages. In: J.F. Muir & R.J. Roberts (Eds.), Recent Advances in Aquaculture, Croom Helm, Ltd., London, UK.
- Beveridge, M.C.M. 2004. Cage Aquaculture (3rd Edition). Blackwell Publishing, Ltd., Oxford, UK.
- Bhaduri K. 1983. Cropsharing as a labor process in Byers, T.J. (Ed.) Sharecropping and Sharecroppers, Frank Cass Publishers, London
- Biswas, S. 1969. Hydrobiology of the Volta River and some of its tributaries before the formation of the Volta Lake. Ghana J. Sc 8: 152-166.
- Bishai H.M. and Khalil M.T. 1997. Freshwater Fishes of Egypt. Egyptian Environmental Affairs Agency (EEAA production), National Biodiversity Unit, No.9, 229 p.
- Bishai H.M.; Abdel Malek S.A. and Khalil M.T. 2000. Lake Nasser. Egyptian Environmental Affairs Agency (EEAA production). National Biodiversity Unit. No.11. 577 p.
- Boyd, C. 1990. Water quality in ponds for aquaculture. Agriculture Experiment Station, Auburn University, Alabama, USA
- Braimah, L. I. (1995). Recent developments in the fisheries of Volta Lake (Ghana). In R.M. Crul and Roest F.C. (Eds.) Current status of fisheries and fish stocks of four largest African resources. CIFA Technical Paper 30. (pp.111-134). Rome: Food and Agriculture Organization.
- Braverman, A. and Srinivasan, T. N. 1981. Credit and Sharecropping in Agrarian Societies. Journal of Development Economics 9(3): 289-312
- Bush, R. 2002. Land reform and counter-revolution. In Bush, R. (Ed.), Counter-revolution in Egypt's countryside: Land and farmers in the era of economic reform, pp. 3-31. New York: Zed Books Ltd
- Capistrano, A.D., Ahmed, M., and Hossain, M. 1994. Ecological, economic and common property issues in Bangladesh's open water and floodplain fisheries. Third Biennial Meeting of the International Society for Ecological Economics. San Jose, Costa Rica, 24-28 October 1994.
- Cheung, S. 1969. The Theory of Share Tenancy, Chicago University Press, Chicago.
- Christensen V., 2005. SCOR/IOC Working Group 119 on Quantitative ecosystem indicators for fisheries management Quantitative Ecosystem Indicators for Fisheries Management. ICES Journal of Marine Science 62 (3).
- CIFRI, 2006 Inventory of reservoirs in the Indian Indo-Gangetic Basin. Project report for the Challenge Programme CP34 "Improved fisheries productivity and management in tropical reservoirs" Central Inland Fisheries Research Institute, (ICAR), Barrackpore, Kolkatta, India, 33 p.

Bibliography CPWF Project Report

- Clarke K.R. and Gorley N.R., 2006. PRIMER v6 User Manual / Tutorial. PRIMER-E, Plymouth, UK, 190 p.
- Costa, H., J. Wijeyaratne M., 1994. Utilization of mangrove species in brush park construction and their effects on Negombo lagoon fishery (Sri Lanka). *Journal of Applied Ichthyology* 10: 96-103.
- Dankwa, H.R., Abban, E.K. and Teugels, G.G. 1999. Freshwater fisheries of Ghana: Identification, distribution, ecological and economic importance. *Annales Sciences Zoologiques*. Vol. 283, 53 p.
- Dankwa, H. R., Agyakwah, S., Agbogah, K., Abban, E. K. and Kolding, J. 2009 Review of catch trends and changes in fish species composition of the Volta Lake during its 45 years of existence. Water Research Institute, Achimota, Ghana
- De-Graaf, G.J. and Ofori-Danson P.K. 1997. Catch and stock assessment in Stratum VII of the Volta Lake. IDAF Technical Report 97/1. FAO Rome, 96 p.
- De La Cruz-Del Mundo, R., P. Del-Mundo, M. Gorospe & R. Macas. 1997. Production and marketing of cage-reared tilapia (*Oreochromis niloticus*) in Taal Lake, Agoncillo, Batangas. pp 633-641. In: K. Fitzsimmons (ed), *Tilapia Aquaculture; Proceedings from the Fourth International Symposium on Tilapia in Aquaculture*, Northeast Regional Agricultural Engineering Service, Ithaca, New York.
- Denyo, F.M.K. 1969. Changes in fish populations and gear selectivity in the Volta Lake pp 206-210. In: Leticia, E. Obeng (ed) *Man-made Lakes*. Ghana University Press
- El-Etriby, S.G. 1982. Studies on the Reproduction Biology of *Lates niloticus* from Lake Nasser. Unpublished Ph.D. Thesis, Alexandria University, Alexandria, Egypt.
- El-Sayed, A.F.M. 2006. *Tilapia culture*. CABI Publishing, Wallingford, UK.
- ENCC, 2006. Egyptian Competitiveness Report 2005-2006, Egyptian National Competitiveness Council, Cairo Egypt.
- Entz, B.A. and Latif, A.F. 1974. Report on surveys to Lake Nasser and Lake Nubia (1972-1973). Lake Nasser Development Center, Aswan, Working paper No 6: 1-137.
- FAO, 1971. Volta Lake Research, Ghana, Physico-chemical conditions of Lake Volta, Ghana. Based on the work of C. W. Czernin-chudenitz. Rome FI:SF/GHA 10, Technical report 1.
- FAO, 2002. *The State of World Fisheries and Aquaculture*. Rome: Food and Agriculture Organization.
- GAFRD 1995-2007. Publications of the General Authority for Development of fish Resources, Ministry of Agriculture. Egypt, (In Arabic).
- Gorissen, G. 1992. Considérations zootechniques et économiques sur l'élevage du Tilapia nilotica en cages à Touro (Katiola), République de Côte d'Ivoire. In: G.M. Bernacsek & H. Powles (Eds.), *Aquaculture Systems Research in Africa*. International Development Research Center, Ottawa, Canada.
- Hambrey, J. 2006. A brief review of small-scale aquaculture in Asia, its potential for poverty alleviation, with a consideration of the merits of investment and specialization. In: M. Halwart & J.F. Moehl (Eds.), *Technical Expert Workshop on Cage Culture in Africa*. Fisheries Proceedings 6. Food and Agriculture Organization of the United Nations.
- Hayes, F.R. 1957. On the variation in bottom fauna and fish yields in relation to trophic level and lake dimension. *J. Fish. Res. Board Can.* 14: 1-32
- Hem, S. and Avit, J. L. B. 1994. First results on acadja-enclos as an extensive aquaculture system (West Africa). *Bulletin of Marine Sciences* 55: 1040-1051.
- IFAD, 2005. Arab Republic of Egypt – Country Programme Evaluation. Report 1658-EG. International Fund for Agricultural Development, Cairo Egypt
- Finegold C., Bénédicte C. Shehata M., Habib, O.A. 2009. Productivity, capital mobilization and moral hazard in fishery: investigating their links through share contract theory in Lake Nasser. submitted
- Johnson G., 1950. Resource allocation under share contracts", *Journal of Political Economy* 58, pp.11-123
- Johnson. 1972. *Economic Analysis, Legal Framework and Land Tenure Systems*. Journal of Law & Economics, University of Chicago Press
- Jul-Larsen, E., Kolding, J., Nielsen, J.R., Overa, R. and van Zwieten, P.A.M. 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
- Khalifa U.S., M.Z. Agaypi and H.A. Adam 2000, Population Dynamics of *Oreochromis niloticus* L and *Sarotherodon galillus* Art. p. 87-90. In J. F. Craig (Ed.) *Sustainable fish production in Lake Nasser: ecological basis and management policy*. ICLARM Conf. Proc.61, 184
- Kolding, J., Musando, B and Songore, N. 2003a. Inshore fisheries and fish population changes in Lake Kariba. p 66-100 In: Jul-Larsen, E., Kolding, J., Nielsen, J.R., Overa, R. and van Zwieten, P.A.M. (Eds.) 2003. Management, co-management or no management? Major dilemmas in southern African freshwater fisheries. Part 2: Case studies. FAO Fisheries Technical Paper 426/2. FAO, Rome.
- Kolding, J., Ticheler, H and Chanda, B. 2003b. The Bangweulu Swamps – a balanced small-scale multi-species fishery. P.34-65. In: Jul-Larsen, E., Kolding, J., Nielson, J.R, Overa, R. and van Zwieten, P.A.M. (Eds.) 2003. Management, co-management or no management? Major dilemmas in southern African freshwater fisheries. Part 2: Case studies. FAO Fisheries Technical Paper 426/2. FAO, Rome.

- Kolding, J. and van Zweiten, P. 2006. Improving productivity in tropical lakes and reservoirs. Cairo, Egypt: Challenge Programme on Food and Water - Aquatic Ecosystems and Fisheries, WorldFish Center, 139 p.
- Kruseman, S. and Vullings, V. 2007. Rural Development Policy in Egypt Towards 2025, Alterra, Alterra-report 1526, Wageningen
- Latif, A.F.A. 1974. Fisheries of Lake Nasser. Aswan Regional Planning, Egypt.
- Latif, A.F. and Khallaf, E.A. 1974. Studies on Nile perch, *Lates niloticus* L., from Lake Nasser. Bull. Inst. Oceanogr. and Fish. A.R.E, 4: 131-64.
- MALR (Ministry of Agriculture and Land Reclamation) – LNDA (Lake Nasser Development Authority). 2001. Commission of enquiry about the optimum way to increase the productivity of the High Dam Lake fishery. translated from Arabic, Cairo: Ministry of Agriculture and Land Reclamation - Lake Nasser Development Authority.
- Laffont, J. and M. Matoussi, 1995. Moral Hazard, Financial Constraints and Sharecropping in El Oulja. The Review of Economic Studies 62(3): 381-399
- Lawson, G.W., Petr, T., Biswas, E.R.T. and Reynolds, J.D. 1969. Hydrological work of the Volta Basin Research Project 1963-1968 IFAN XXXI, série A. 3(9): 65-1003
- Lévêque, C., Fairhurst, C. P., Abban, E.K. Paugy, Curtis, S., and Traore, K. 1988. Onchocerciasis Control Programme in West Africa: Ten years of monitoring of fish populations. Chemosphere 17(2): 421-440.
- Li, Y. 1994. On the status and development strategies of reservoir fisheries in China. Reservoir Fisheries 3, 3-5 (in Chinese)
- Lorentzen, K., Amarasinghe, U.S., Bartley, D.M., Bell, J.D., Bilio, M., de Silva, S.S., Garaway, C.J. Hartman, W.D., Kapetsky, J.M., Laleye, P., Moreau, J., Sugunan, V.V., and Swar, D.B. 2001. Strategic review of enhancement and culture based fisheries. In Subasinghe, R.P., Bueno, P.B., Phillips, M.J. Hough, C, McGladdery, S.E., and Arthur, J.R. (eds.). Aquaculture in the third millennium. Technical proceedings of the conference on aquaculture in the third millennium, Bangkok, Thailand. 2025 February 2000. NACA, Bangkok and FAO, Rome. pp. 211-237.
- Massoud, A.A.; Shenouda, Th.S. and Wadie, W.F. 1985. Biological study of the tiger fish *Hydrocynus forskalii*. Cuv., from Lake Nasser. Delta J. Sci. 9(2): 537-562.
- Mekkawy, I.A. 1998. Fish stock assessment of Lake Nasser, Egypt with emphasis on the fisheries of *Oreochromis niloticus* and *Sarotherodon galilaeus*. J. Egypt. Ger. Soc. Zool 35(B): 283-404.
- Mikolasek, O., J. Lazard, M. Alhassane, P. Parrel and I. Ali. 1997. Biotechnical management of small-scale tilapia production units in floating cages in Niger River (Niger). pp.348–356. In: K. Fitzsimmons (ed), Tilapia Aquaculture; Proceedings from the Fourth International Symposium on Tilapia in Aquaculture, Northeast Regional Agricultural Engineering Service, Ithaca, New York.
- Misund, O.A., Kolding, J. and Fréon, P. 2003. Fish capture devices in industrial and artisanal fisheries and their influence on management. In P.J.B. Hart and J.D. Reynolds (eds.). Handbook of Fish Biology and Fisheries, vol. II, Blackwell Science, London. pp. 13-36.
- MOFA. 2003. Fisheries Management Plan for the Lake Volta, Ghana. 75pp
- Morrow, James D. 1994. Modeling the Forms of International Cooperation: Distribution Versus Information. International Organization 48: 387-423.
- Mohieddin, M.M. 2000. Some Socioeconomic Aspects. In J.F. Craig (Ed.) Sustainable Fish Production in Lake Nasser: Ecological Basis and management Policy, ICLARM Conf. Proc. 61, International Center for Living Aquatic Resources Management, Penang
- Ntow, W.J. 2003. The limnological conditions of the northern portion (Yeji area) of the Volta Lake 30 years after impoundment. Tropical Ecology 44(2): 263-265.
- Ofori-Danson, P.K and Ntow, W.J. 2005. Studies on the current state of the limno-chemistry and potential fish yield of Lake Volta (Yeji sector) after three decades of impoundment. Ghana J. Agric. Sci. 35: 65-72.
- Ostrom, E. (1990). Governing the Commons: the evolution of institutions for collective actions. Cambridge: Cambridge University Press.
- Paugy, D., Fermon, Y., Abban, E.K., Diop, M.E. and Traore, K. 1999. Onchocerciasis Control Programme in West Africa: a 20-year monitoring of fish assemblages. Aquatic Living Resources, 12(6): 363-378
- Paugy D., Lévêque C. and Teugels G. G., 2004. Poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest, édition complète. Tome I & II. Edition IRD, MNHN, MRAC, 458 + 816p
- Platteau, J.P. and Nugent J., 1992. Share Contracts and their Rationale: Lessons from Marine Fishing Journal of Development Studies, vol. 28(3): 386-422
- Rashid, M.M. 1977. On the Biology of Fishes of Genus *Alestes* in Lake Nasser, Egypt. Ph.D. Thesis, Cairo University, Egypt.
- Rawson, D.S. 1952. Mean depth and fish production in large lakes. Ecology 33: 513- 521.
- Runge, C.F. 1984. Institutions and the Free Rider: The Assurance Problem in Collective Action. The Journal of Politics 46 (February): 154-181.

Bibliography CPWF Project Report

- Runge, C.F. 1992. Common Property and Collective Action in Economic Development. In (Eds.) Bromley D., Feeny D., McKean M.A., Peters P., Gilles J.L., Oakerson R.J., Runge C.F. and Thomson J.T. Making the Commons work, pp.17-41. San Francisco: Institute for Contemporary Studies.
- Sargeson, S. 2002. Collective Goods, Collective Futures in Asia. Routledge. London
- Seabright, Paul. 1993. Managing Local Commons: Theoretical Issues in Incentive Design. *The Journal of Economic Perspectives* 7: 113-134.
- Sinha, M. and Katiha, P.K. 2002. Management of inland fisheries resources under different property regimes. In Marothia D.K. (Ed.) *Institutionalizing Common Pool Resources*, Concept Publishing Company, New Delhi. pp.437-460.
- Sugunan, V. 1995. Reservoir fisheries in India. FAO Fish. Tech. Paper 345, Food and Agricultural Organization, Rome, 423 p.
- Sugunan, V., Welcomme, R., Béné, C., Brummett, R. Beveridge, M., 2007. Inland fisheries, aquaculture and water productivity. pp.459-484 In: Molden D. (Ed.), *Water for Food, Water for Life - Comprehensive Assessment for Agricultural Water*. Earthscan, London.
- Tharwat, S. Abbass, F. Rashid, M. 1994. The use of five prolongation of the spawning season of the partially spawning fishes of genus *Chrysichthys* from Aswan Reservoir Egypt. *J. Union. Arab. & W.* (1A): 17-45.
- Ticheler, H., Kolding, J, and Chanda, B. 1998. Participation of local fishermen in scientific fisheries data collection, a case study from the Bangweulu swamps, Zambia. *Fish. Man. and Ecology* 5: 81-92
- UNDP 2004. Egypt Human Development Report 2004: Choosing Decentralisation for Good Governance. United Nations Development Programme and Institute of National Planning, Egypt
- Viner, A.B. 1969. Observations of the hydrobiology of the Volta Lake (April 1965-April 1966) In: Obeng, L.E. (ed) *Man-made Lakes*. [Proc. of the] Accra Symposium. Accra: Ghana University Press.
- Van Densen, W.L., Kechik I., Baluyut, E.A. Chookajorn, T. Moreau, J. Sarnita, A.S. Yap, S.Y. et al. (1999). Fish production, catch composition and changes in the freshwater fish communities in ASEAN lakes and reservoirs, In van Densen W.L. and M. J. Morris. (Eds.) *Fish and fisheries of lakes and reservoirs in Southeast Asia and Africa*, pp.229 – 244. Otley, West Yorkshire, UK, Westbury Academic & Scientific Publishing
- van Zwieten P.A.M. C. Béné, J. Kolding, and R. Brummett ,2009. Review of tropical reservoirs and their fisheries in developing countries: the cases of the Lake Nasser, Lake Volta and Indo-Gangetic basin reservoirs. Project CP34 Improved fisheries productivity and management in tropical reservoirs (project coordinated by the WorldFish Center)
- Welcomme, R.L., 1971. A description of certain indigenous fishing methods from Southern Dahomey. *African Journal of Tropical Hydrobiology and Fisheries* 2: 128-140.
- Welcomme, R. L. 1964. The habitats and habitat preferences of the young of the Lake Victoria Tilapia (Pisces: Cichlidae). *Rev. Zool. Bot. Afr.* 70: 1-28
- Yi, Y., C. Kwei Lin & J. Diana. 1996. Influence of Nile tilapia (*Oreochromis niloticus*) stocking density in cages on their growth and yield in cages and in ponds containing the cages. *Aquaculture* 146:205-215.
- Zeller, M. & M. Sharma, 1998. *Rural Finance and Poverty Alleviation*. International Food Policy Research Institute, Washington, DC

PROJECT PARTICIPANTS**NARES***Central Inland Fisheries Research Institute (India)*

Principal Investigator: Dr Kuldeep K. Vass

Pradeep Katiha

Dr. Archan K. Das

Dr. Narbada P. Shrivastava

Lake Nasser Development Authority (Egypt)

Principal Investigator: Dr. Olfat A. Habib

Mr. Mohamed Shehata

Mr. Murad Zaki

Dr. Hussein Ammar

Miss Amany Abd El Rassoul

Mr. Iwamoto –JACA Senior volunteers

National Institute of Oceanography and Fisheries (Egypt)

Principal Investigator: Prof Soliman H. Abdel-Rahman

Radwan Gad El Rab Abdel Elah

Dr. Alaa ElDin El Haweet

Mr Hisham Abdel Mawla

Water Research Institute (Ghana)

Principal Investigator: Dr. Eddie K. Abban

Dr Nelson Obirih-Opareh

Mr. Joseph K. Ofori

Mr. Hederick R. Dankwa

ARI*University of Bergen (Norway)*

Principal Investigator: Dr Jeppe Kolding

CG-center*WorldFish Center (Malaysia)*

Project Leader: Dr Chris Béné

Dr Randall Brummett

In addition the following persons have contributed to the project activities: Dr. Adel Aly Ahmad (NIOF), Mr. H. Ammar (LNDA), Mr. Surajit Kangsa Banik (IGFRI India), Mr. Satish Kumar Bara (CIAE India), Mr. Partho Pratim Bhadra (CIFRI), Mr. Nirmal Kumar Biswas (CIAE India), Mr. Bikash Chaudhari (CIFRI), Mr. Ram Prasad Choudhury (CIFRI), Dr. M. I. Khan, Bundelkhand University (India), Dr. Reda Fishar (NIOF), Dr. Alaa M. El Far (NIOF), Mr. Yaser El Sangak (NIOF), Dr. Emad Hamdy (NIOF), Dr. Ola Ezz ElDin Taha (NIOF), Mr. Shubhodeep Ghosh (CIFRI), Dr. Mohammed Hamdy (NIOF), Prof. Jacques Lemoalle (IRD- UMR G-Eau France), Dr. Mohammed Saad Abdel Kariem (NIOF), Shri M. Karthikeyan (CIFRI), Mr. Tilak Singh Kushwaha (CIAE India), Mr Shyam Lal Arya (IGFRI), Shri S. K. Mandal (CIFRI, Barrackpore), Ms Anandita Mondal (CIFRI), Mr M. Nageb (LNDA), Mr I. Omar (LNDA), Miss Amany Abd El Rassoul (LNDA), Dr. D.S. K. Rao (CIFRI), Mrs Anubha Saxena (CIFRI), Ms Sanchita Sarkar (CIFRI), Dr. V. K. Sharma (CIFE, Mumbai), Mr. Chandrashekhara Singh (CIAE India), Mr. Prashant Singh (CIFRI), Ms Ankita Sharma (IGFRI India), Dr. V. V. Sugunan, (ADG, IACR, New Delhi); Dr. M. K. Pal, Vidyasagar University (India), Dr. Aly Yousef (NIOF), Dr. Shawki Zaki Sabaa (NIOF), Dr. Ashwani Wangneo (Barkatulla University India), Mr. M. Zaki (LNDA), Prof. Paul van Zwieten (Wageningen University, Netherlands).

APPENDIX : ABSTRACT OF PEER-REVIEWED PUBLICATIONS

Abd Ellah RG. 2008. Physical Limnology of two enclosures in Lake Nasser, Egypt. *Egyptian Journal of Aquatic Research* 34(4): 247-259

The aim of this work is to plot bathymetric charts, determine the changes in morphometry (water depths and surface area), and some physico-chemical properties of two enclosures in Lake Nasser. The surveys of the two enclosures were carried during July 2007 and March 2008. The surface water area of Emberckab Enclosure increased from 0.28 million m² in summer with maximum depth 7.6 m to 1.27 million m² with maximum depth 13.4 m in winter. At Wadi Abyed Enclosure, the surface water area increased from 2.11 million m² in winter with maximum depth 35.1 m in summer to 2.13 million m² in winter with maximum depth of 40.1 m. The results of the study showed that the water depth and consequently water area of the enclosures are low in summer and high in winter depending on the flood quantity and consequently the Lake's level and surrounding land topography. Concerning the environmental parameters in the two enclosures, the results revealed that the temperature, transparency, EC, TDS and pH values are high before the flood season (summer) and low after the flood season (winter). The temperature, EC, TDS and pH values at the entrance are lower than those inside of the enclosures.

Béné C., Bandi B. and Durville F. 2008, Liberalization reform, 'neo-centralism' and black market: insight into the political economy of Lake Nasser fishery development. *Water Alternative* 1(2): 219-235.

Despite its relatively modest importance, and the current difficulties faced by the government in implementing liberalization in the rest of the country, the Egyptian government decided to embark on a reform of the Lake Nasser fishery in the early 2000s. The objective of this article is to analyse the evolution of this reform from a political economy perspective. The paper looks retrospectively at the general context of the reform, describes the different institutional and economic changes that have resulted from its realization, identifies how the distribution of power between the different actors has altered the course of its implementation, and finally assesses the outcomes of the reform. The analysis shows that, while some major institutional changes have taken place, those changes have had little to do with a 'liberalization' as conventionally understood in neo-classical literature. Instead, the new status quo turns out to be one where the central government and its different parastatal agencies have managed to maintain their existing advantages. The failure to reform more thoroughly the system also led fishers and fish traders to engage in a large-scale black market activity in which a substantial amount of fish is smuggled through unofficial trade channels.

Béné C. and Obirih-Opareh N., Social and economic impacts of agricultural productivity intensification: the case of brush park fisheries in Lake Volta. *Agricultural Systems* (accepted)

The intensification of agricultural productivity through technological innovation has often been reported to induce considerable social and economic transformation in the rural communities where those innovations are introduced. This article investigates those changes in the case of *acadja*, a particular intensifying fishing technique adopted in various parts of the developing world. Using the case of the Lake Volta in Ghana, the paper investigates the social and economic impacts of this technique, looking in particular into issues of income, assets and (re)distribution of the wealth created by those *acadjas*. Our analysis shows that the impact of *acadjas* on the fishing communities is mixed. While *acadja* certainly helps enhancing the supply of protein-rich food and may have trickle down effects at the community level, those positive contributions are greatly reduced by other more negative effects. The data shows in particular that *acadjas* are not a poor-neutral technology in the sense that their contribution to household income seems to benefit disproportionately the wealthiest owners. As such, *acadja* fisheries often create negative sentiments amongst the households who cannot afford investing in this technology, creating a situation which may lead to social tension and intra-community conflicts.

Finegold C., Béné C. Shehata M., Habib, O.A. 2009. Productivity, capital mobilization and moral hazard in fishery: investigating their links through share contract theory in Lake Nasser (submitted)

This paper examines contractual relations in Egypt's Lake Nasser fishery, seeking to understand why so many seemingly redundant contract types coexist and what effect they have on productivity. Based on the results of a recent socio-economic survey conducted in the fishery and drawing on the existing literature on agricultural sharecropping and on share remuneration systems in fisheries, the paper analyzes the roles of the different contractual relations observed in the Lake Nasser fishery. In particular, it discusses the incentives, limitations, and opportunities that these contracts offer to the different groups of actors (gear owners, crew members), and shows how these arrangements influence and shape the fishing strategies, capital mobilization, and ultimately labor productivity of those different groups. While the debate on share contracts generally emphasizes their efficiency relative to other types of contracts, particularly in terms of the options they provide for sharing risk and the incentives they hold, our analysis provides a more nuanced explanation, highlighting in particular how they contribute to meeting the production needs of the varied range of actors present in the fishery.

El Haweet A., El Hussein A., Sangq Y., and Elfar A. 2008. Assessment of Lake Nasser Fisheries. *Egyptian Journal of Aquatic Research* 34(2): 285-298

Four fisheries surveys were carried out in Lake Nasser, the largest lake in Egypt (about 6000 km²), in order to assess the lake fisheries during the period from March 2006 to March 2008. Random fishing boats were inspected to investigate their fishing gears and methods (e.g. trammel and gill nets) and their catches. Artisanal fishery in the lake is conducted nearer to the shoreline in areas not more than 15m deep targeting only 6 species. The most dominant species were; Tilapia group (*O. niloticus*, *S. galilaeus*, and *T. zillii*), pelagic fishes (*A. dentex* and *H. forskalii*) and *L. niloticus*. A size-range of each species and their distribution pattern in different areas of the lake was described for the major fish species in the lake. The time series of size distribution showed high exploitation rate for most important commercial species in the Lake. Catch per unit effort (CPUE) of different fishing methods in the Lake was estimated as the catch in Kg of fish by 50m length of the nets per night or shot. The results indicate that the southern part of the lake is more productive for gill net while the opposite is recorded for trammel net. Unreported landings are still considered to be a major problem in the landing estimate of the lake which is used as a tool for fisheries management. Options for the management of Lake Nasser fishery are suggested.

Ofori J.K., Abban E.K., Karikari A.Y. Brummett R.E. Production economics of small-scale tilapia cage aquaculture in the Volta Lake, Ghana. *Journal of Applied Aquaculture* (in press)

To calculate the potential for cage aquaculture to create economic opportunities for small-scale investors on the Volta Lake a local NGO with technical support from the Government of Ghana ran 10 trials of small-scale cage aquaculture in the town of Dzemeni. Cages were built locally from available materials at a cost of approximately US\$1000 per 48m³ cage. An indigenous line of mixed sex Nile tilapia, *Oreochromis niloticus*, was stocked at an average rate of 103 fish/m³ and grown on locally available pelleted feeds for approximately 6 months. Total costs averaged US\$2038 per six-month production cycle. Gross yield ranged from 232 to 1176 kg/cage averaging 460 kg/cage (9.6 kg/m³). Mortality resulting primarily from poor handling during transport and stocking averaged 70% and was a major determinate of production and profitability. To break even, harvested biomass of fish needed to exceed 15 kg/m³. At 25 kg/m³, small-scale cage aquaculture generated a net income of US\$717 per cage per six months (ROI =30.2%) on revenues of US\$3,500. Water quality in the area surrounding the cages was not negatively affected by aquaculture at the scale tested (5 tons of feed per six months).