SUSFISHBook

Sustainable Fisheries and Water Management Transformation Pathways for Burkina Faso

1st Edition – 2020

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SUSFISHBook

Sustainable Fisheries and Water Management

Transformation Pathways for Burkina Faso

Lessons learnt from APPEAR Projects [56] and [166] SUSFISH and SUSFISH+

Sustainable Management of Water and Fish Resources in Burkina Faso

The Austrian Partnership Programme for Higher Education and Research for Development (**APPEAR**) supports higher education and research partnerships between institutions in Austria and the partner countries of Austrian Development Cooperation. Since 2010, APPEAR supported 43 partnerships in 20 countries as well as 126 scholarships, mainly for PhD studies in Austria. The design and implementation of projects is led by the programme's guiding principles: participatory approach, culturally open-minded knowledge, practically and empirically oriented approach, gender sensitivity as well as bottom-up and demand-driven approach. Further information: www.appear.at

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Opening Remarks from Burkina Faso

In Burkina Faso, despite relatively limited water resources, fishing and aquaculture play an increasingly important role in the national economy. For the poorest populations this is especially evident due to the fish contribution to nutrition, employment, reduction of rural exodus, the reinvestment of income from fish in agriculture (inputs), livestock breeding (e.g. poultry and small ruminants), and small business.

Aware of that challenges of sustainable management of fishery resources require a better knowledge in fishing and aquaculture to better guide decision-making for policy and planning, the Government has adopted a national policy and a national strategy in 2013 (Strategy for the Sustainable Development of Fisheries and Aquaculture by 2025) to boost the development of this sub-sector. One of the strategic areas is the contribution of research for development.

For almost 10 years my department has benefited from support from the research project named SUSFISH and SUSFISH-Plus that stands for Sustainable Management of Fish Water and Fish Resources in Burkina Faso. This project was able to give answers to critical questions, to diagnose a number of problematical situations in the hope of better and sustained national production of fish.

As results, the project produced scientific publications, evaluated the conservation status of the country's fish species, studied the impact of policies and legislations in the management of fishery resources, analysed the value chains in fisheries, proposed solutions for to promote fish farming and raised gender awareness in fisheries.

In this regard, I would like to express my gratitude to both national scientific partners (INERA, University Joseph KI ZERBO, University NAZI BONI, IUCN, the General Directorate for Fish Resources) and international partners (University of Natural Resources and Life Sciences in Vienna, University of Vienna, International Institute for Applied Systems Analysis) and financial partners (Austrian Programme for Higher Education and Research implemented by the OEAD and financed by the ADA) for their very relevant and important contribution in giving insight to the improvement and implementation of national policy in fisheries and aquaculture.

Au Burkina Faso, malgré les ressources en eau relativement limitées, la pêche et l'aquaculture jouent un rôle de plus en plus important dans l'économie nationale. Cela se manifeste, surtout pour les populations les plus pauvres, par sa contribution qualitative dans la nutrition, l'emploi, l'apport en revenus non négligeables réinvestis dans l'agriculture (intrants), l'élevage (volaille, petits ruminants, …) et le petit commerce et dans la réduction de l'exode rural.

Conscient du fait que les enjeux de gestion durable des ressources halieutiques exigent une meilleure connaissance de la pêche et de l'aquaculture en vue de mieux guider la prise de décisions au niveau politique et règlementaire, le Gouvernement a adopté en 2013 une politique nationale assortie d'une stratégie de développement durable de la pêche et de l'aquaculture à l'horizon 2025 pour booster le développement de ce sous-secteur. Il est prévu entre autres axes stratégiques dans ce document, la recherche développement.

Mon département a bénéficié depuis près de 10 ans d'un accompagnement du projet Susfish et Susfish Plus, financé par la Coopération Autrichienne pour Développement, qui a permis de répondre à certaines questions, d'éclairer bien de situations et d'ouvrir d'autres chantiers pour mieux diagnostiquer les problématiques du sous-secteur et accroitre quantitativement et qualitativement la production halieutique.

Je retiens entre autres résultats de la série de publication, l'évaluation du statut de conservation des espèces de poisson du pays, l'impact des politiques et des règlements sur la gestion des ressources halieutiques, les chaînes de valeurs dans ce secteur d'activés, des pistes de solutions pour la promotion de la pisciculture, les questions genres… .

Je voudrais à cet égard, manifester ma gratitude aux partenaires techniques aussi bien nationaux (INERA, Université Joseph KI ZERBO, Université Nazi BONI, UICN) qu'internationaux (BOKU-University of Natural Resources and Life Sciences, University of Vienna, International Institut for Applied Systems Analysis) et financiers (Programme Autrichien pour l'Enseignement Supérieur et la Recherche mis en œuvre par l'OEAD) pour leur apport combien pertinent dans la mise en œuvre de la politique nationale permettant de donner des orientations appropriées pour le développement de la pêche et de l'aquaculture au Burkina Faso.

Sommanogo KOUTOU

Sommanogo Koutou

Le Ministre des Ressources Animales et Halieutiques (The Minister of Animal and Fishery Resources)
Officier de l'Ordre National (Officer of the National Order)

Opening Remarks from Austria


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With this publication, the team of collaborators of the APPEAR SUSFISH project presents the results of its work, spanning a period of six years. In the way SUSFISH was conceived and its results are presented to a wider audience, the project is exemplary to what our flagship programme for higher education and research for development strives to achieve: the generation of scientific knowledge to help overcome developmental challenges and improve the lives of communities.

Burkina Faso has an untapped potential to improve food security and livelihoods through the management of inland water bodies, the professionalization of fish production and the development of value chains related to the production, processing and distribution of fish. The information and evidence presented in this book have been compiled with both policy decision making and community level intervention in mind. With chapters related to history, ecology, sociology and economy of water and fishery management, this publication offers pertinent insights and recommendations for the development of the sector, including further academic work.

On behalf of the Austrian Development Cooperation and APPEAR, I commend all efforts of the SUSFISH team. I trust that this publication will find wide circulation and be a valuable resource to academic and non-academic stakeholders in our partner country Burkina Faso and beyond.

Dr. Martin LEDOLTER, LL.M.

Managing Director Austrian Development Agency (ADA), the operational unit of Austrian Development Cooperation

Foreword

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The Austrian Partnership Programme in Higher Education and Research for Development (APPEAR) has been promoting scientific cooperation between universities in Austria and the partner countries of the Austrian Development Cooperation (ADC) for ten years now. The projects supported by APPEAR are selected through a competitive qualification process, with consideration of the five basic principles of the programme, namely a participatory approach; a concept of culturally open-minded knowledge; a practically- and empirically oriented approach; gender sensitivity; and lastly a bottom-up and demand-driven approach.

The SUSFISH project is special because it has been successful in two selection processes. It started during the first phase of the APPEAR programme as Academic Partnership (2011-2014) and continued as Advanced Academic Partnership (2016-2020) in the second phase of APPEAR. From the results of the successfully completed APPEAR project, new qualitative objectives were defined, and the scientific collaboration has been continued. Furthermore, the acquired experiences from the first phase could be used to strengthen sustainable research and teaching structures at the involved institutions. In this way, APPEAR supported capacity building and research on sustainable management of water and fish resources in Burkina Faso for more than seven years.

In reality, the cooperation towards the SUSFISH project began much earlier when Dr. Raymond Ouedraogo, the national project coordinator undertook his doctoral studies, also financed by ADC, at the University of Natural Resources and Life Sciences (BOKU), Vienna. The idea of the project originated from the results of his doctoral thesis undertaken in collaboration with his academic supervisor Dr. Andreas Melcher in Austria. Upon successful completion of his studies Raymond Ouedraogo resumed his work in Burkina Faso at the Department of Fisheries, Ministry of Environment and Sustainable Development, where he was able to bring on board other important institutions, such as the Department of Biology of the University of Ouagadougou, the Department of Sociology and the Department of Health of the University of Bobo-Dioulasso and the International Union for Conservation of Nature of West Africa (IUCN).

Through this consortium, the SUSFISH project was able to involve different stakeholders to integrate perspectives from science, politics and practice. Inter- and multidisciplinary methodologies to assess and analyse ecological, social and economic aspects for the proper management of water and fish resources were also included and successfully applied. The findings of this initiative have been published as policy papers, technical reports, and scientific articles, discussed within local and research communities. They have also been integrated into the curricula of universities and into the design of the water and fisheries policies for Burkina Faso. The SUSFISH project is hence a good model for research uptake and the use of scientific findings to support sustainable institutionalization of accomplishments by the participating institutions. There is also the potential to further enhance and upscale these findings through the established innovation platform. Within these achievements, an example of applied research is the exchange between local stakeholders in the fisheries and water management sector and students of the International Master Programme that was established during the project time, where mutual learning is a core element.

In terms of capacity building, an important objective of the APPEAR programme, a number of students have been trained in Austria and Burkina Faso. Bachelor's, Master's and PhD students were supported for studies at Burkinabe institutions while some Austrian students also got the opportunity to complete their research stays in Burkina Faso. Two PhD students, nominated for an APPEAR scholarship within the project, have already completed their doctorate at BOKU. The students, who are back in Burkina Faso, have been employed as lecturers at the university and are presently working as researchers within the SUSFISH project to support its activities with their acquired skills and expertise. One APPEAR scholarship holder is also currently finalising his PhD thesis on *"Traditional fisheries practices in transition".*

The present book is the result of the commitment of many researchers, community representatives, policymakers and students and showcases the research efforts and capacity building initiatives over the last couple of years. Hence, it is fair enough to say that some scientific gaps in water and fish resources management have been filled, potentially contributing to a more sustainable Burkina Faso, now and in the future.

DI Elke STINNIG, BA

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Preface

This book results from ten years of development research in the fisheries and waters of Burkina Faso. The work was carried out by a consortium of researchers and developers dealing with fish in Burkina Faso (Institute for Environment and Agricultural Research, University Pr. Joseph KI-ZERBO, University Nazi BONI, International Union for the Nature Conservation and General Directorate for Fish Resources) and Austria (University of Natural Resources and Life Sciences, University of Vienna) with the financial assistance of the Austrian Partnership Programme in Higher Education and Research for Development. They all worked as team in the framework of the Project named SUSFISH that stands for Sustainable Management of Water and Fish Resources in Burkina Faso. This 2nd-phase undertaking lasted from 2011 to 2014 and from 2016 to 2020. Detailed information on the project is available on www.susfish.boku.ac.at.

As an arid country, Burkina Faso has implemented a programme of reservoir creation with the purpose of providing water to people for any use. As a result, more than 1500 bodies of water are currently used for irrigation, livestock breeding, domestic needs, industrial usages, power generation and fishing. For quite some time, fishing was not taken into consideration in the planning and valuation of reservoir creation. However, nowadays, fishing and aquaculture are gradually included in the complementary purposes of water resource development, especially for large size reservoirs. Therefore, and in line with national policies for development, the goal of the SUSFISH project has been to build capacity in fisheries management, by providing reliable information and strengthening human resources.

The present publication reflects work that continues from the cooperation between Austria and Burkina Faso that started around 1960 with a professional training programme for the Burkinabe youth. Yet, in the SUSFISH Project, the development of human resources targeted mainly higher education by improving curricula in water- and fisheries-related domains, and by contributing to the supervision of students' studies and research in Burkina and in Austria.

The commitment of the project members to work together and to tackle actual problems in the fisheries sector yielded interesting results covering facets of the natural, political and the human sciences related to Burkinabe fisheries and aquatic ecosystems. This research encompassed systemic assessment of how links and interactions within and between these facets affected Burkinabe fisheries, including threats to the Burkinabe aquatic ecosystems, climatic changes, fish and benthic macroinvertebrates, and the socio-economic sides. This book does not pretend to give a full description of the Burkinabe fisheries and water. But at least it gives insight and stimulation for development and research in that sphere thus giving an understanding to socio-economic development of African inlands waters.

The book ends with recommendations to guide the development of science and policy for a better future in fisheries. This critical summary follows from the new political trend to have a long-term vision for fish resources development as shown by the current national fisheries strategy.

Andreas H. MELCHER and Raymond OUEDRAOGO

SUSFISH overall coordinators and editors

Editors meeting 2019, Ouagadougou (from left to right: Patrice Toe, Andreas Melcher, Gabriele Slezak, Adama Oueda and Raymond Ouedraogo) ©Elke Stinnig

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1. Summary and Aim of SUSFISH Projects

The research projects Sustainable Management of Water and Fish Resources (SUSFISH and SUSFISH+) aim to produce reliable knowledge which can be used to help improve policies, management, research and education so as to make fisheries more sustainable in Burkina Faso. The topics of research include ecology, policies and socio-economy in fisheries and covers the entire national territory. By producing and institutionalizing knowledge about aquatic ecosystems, water and fisheries management, SUSFISH is helping to build capacities in local fisheries so as to help secure food production, nutrition and development in Burkina Faso. The Project took place in two phases; SUSFISH (2011-2014) and SUSFISH+ (2016-2019). SUSFISH was designed as a partnership between academic, governmental and local organisations in Austria and Burkina Faso. The project is funded through the APPEAR Programm (Austrian Partnership Programme in Higher Education and Research for Development) from the Austrian Development Agency (ADA) and implemented by the OeAD (Austrian Agency for International Cooperation in Education and Research).

The leading partners cooperating in this Project are:

- BOKU – University of Natural Resources and Life Sciences, Vienna
    - IHG – Institute of Hydrobiology and Aquatic Ecosystem Management
    - IDR – Institute for Development Research
- University of Vienna – Department of African Studies
- UJKZ – Université Joseph Ki-Zerbo (UJKZ), Ouagadougou, Laboratory of Animal Ecology and Biology
- UNB – Université Nazi BONI, Rural Development Institute (IDR)
- INERA – Ministry of Research, Institute for Environmental and Agricultural Research
- IUCN – International Union for Conservation of Nature, Burkina Faso Office
- GDFR – Ministry of Animal and Fish Resources, General Directorate for Fish Resources
- IIASA – International Institute of Applied Systems Analysis, Risk and Resilience Program (RISK).

As a result of SUSFISH, methods and tools have been developed for standardized assessment of water and river network health as well as tools to measure environmental impacts on riverside society. The focus of the preceding project SUSFISH+ was based on information sharing between experts and stakeholders of fisheries and water management by establishing an innovation platform and developing an integrated education and research program. The SUSFISH+ participatory research process allowed academic experts to explore with non-academic stakeholders from government, NGOs and business how interactions between biophysical and social factors may influence a river basin's potential for sustainable development.

2. Introduction

Humankind impacts the environment and aquatic ecosystems more than any other species (Vitousek *et al*., 1997), as can be seen by historical human settlements near watercourses and waterbodies (Baron *et al*., 2002). As ecological awareness grows around the world, we are often inclined to take a retrospective look at the impact that humans have on nature. Like many developing countries, Burkina Faso maintained a productivist bias for decades before realizing that environmental protection should be taken into account in any development activity.

In response to threats of chronic water shortages intensified by episodes of severe drought and few permanent water courses, hundreds of reservoirs have been built in Burkina Faso since 1950. This harnessing of the aquatic system enabled the expansion of agriculture and the water supply as well as the increased production and consumption of fish. These benefits have also come with increased pressures on the man-made aquatic system posing a threat to the long-term health of these waterbodies. Ranking in the bottom five percent of all countries on the UN Development Index, Burkina Faso has a need for sustainable development. Given the natural (e.g. chronic water scarcity and episodes of severe drought) and socio-economic (e.g. extreme poverty) constraints, sustainable fish- and water management is central to national development policies and strategies.

Decisions about how to implement sustainable management practices to better achieve sustainable development goals requires the means to monitor and measure progress of socio-economic and environmental indicators as well as political frameworks. SUSFISH and SUSFISH+ offered such means in the form of methods and tools for the standardised assessment of water and river health as well as an analysis of socio-economic, political and environmental factors influencing aquatic ecosystems and riverside society. These are part of a science-based approach that provides feedback between the impacts of practices on the ground and policy-making to ensure the long-term protection of aquatic resources while also generating social welfare.
With a focus on capacity building, the SUSFISH Projects aimed to provide reliable data and information on aquatic ecosystems and the associated living communities for sustainable management as well as creating a basis for exchange and cooperation between the stakeholders involved.

This book is a summary of selected findings in the two projects SUSFISH and SUSFISH+. It is an introduction into the diverse questions and findings of the SUSFISH team members in Burkina Faso and in Austria. Topics range from the tradition, history and development of fisheries in Burkina Faso, to the use of bioindicators for ecosystem assessment as well as an introduction to monitoring methodology and aquatic species diversity. This is put into an environmental and socio-economic context through discussion of climate change and other pressures on aquatic ecosystems but also the implications of gender, governance and an analysis of the complete value chain of fish production. As a conclusion research into aquaculture and policy recommendations suggest a way forward for sustainable fisheries and water management.

As a compilation of findings in the SUSFISH and SUSFISH+ projects, the results and sections displayed in this book rely on the work completed in the students' master and doctoral theses, as well as reporting and reflections within the SUSFISH projects.

2.1. History and Tradition in Fisheries in Burkina Faso

Vincent-Paul Sanon, Patrice Toé, Laura Hundscheid and Raymond Ouedraogo

Fishing is an immemorial practice. Together with hunting and gathering, it was for many millennia the source of food for the first humans (Ki-Zerbo, 1978; Verdeaux, 1992). The modern descendants of Tanzania's cichlid Tilapia and catfish appeared with *Homo habilis* and later *Homo erectus* more than 500 000 years ago in East Africa. Wall and rock paintings also provide evidence of the interaction between men and fish about 40 000 years ago that suggest fish were used as food and for rituals (Gartside, 2009). With the evolution of *Homo sapiens* in the Upper Palaeolithic, fishing with tools or as a community activity emerged between 40 000 and 10 000 BC. Spears, nets and fishing rods first appeared around 3500 BC in Egypt (Gartside, 2009 and Paugy *et al.*, 2011).

According to Couty (1989), research into the social and economic aspects of fishing and the fish trade in Francophone Africa date back to the colonial period, at least in the Chad Basin (Couty, 1989). As early as 1925, a research plan submitted to governor Marchand, high commissioner of the French Republic in Cameroon, first provided systematic investigations into fish and aquatic fauna but also a review of indigenous fishing methods; then a study on the main fishing centres and "races of fishers"; lastly, an economic study of fish consumption, measures to be recommended to intensify fishing and possibilities of exploitation of fauna by the colonizing country.

However, since the development of fishing as a commercial activity in Burkina Faso has only recently taken place, the history of fisheries development in the country has hardly been researched. This results in a knowledge gap about the different fishing methods in the country and the different stages of the development of commercial fishing, as well as relevant institutional changes. This chapter summarizes some important phases of fishing development in Burkina Faso, based on literature and our research about fisheries governance within SUSFISH project.

Traditional Fishing and Water Management

Several authors affirmed there is no real 'fishing tradition' in Burkina Faso (Blin, 1977; Breuil, 1995; Toé, 1999; Béné, 2007). This assertion is based on the argument that, unlike other regions such as the central delta of Niger, no ethnic group had specialized in fishing. This is mainly due to the fact that Burkina Faso did not contain any standing water bodies of sufficient size or depth to support professional fishing activities (Kassibo, 2000; Béné, 2007). Thus, until the end of the 1950s, Burkina Faso had few professional fishermen (Zerbo *et al*., 2002; Béné, 2007). However, in the pre-colonial past, many local communities developed fishing practices and techniques on rivers and smaller watercourses. The activity of the fishery was mainly customary and took place once a year, when watercourses ran low just before the start of the rainy season. Fishing was collective and with rudimentary tools such as cutters, traps and baskets (Baijot *et al*., 1994; Jacob, 2003; Jacob 2007)

In this form of management, the traditional institutions of governance oversaw resource access, exploitation and sustainability. This implies both rituals and prohibitions inscribed in the beliefs but also the hierarchy of authority that directed those rituals to enforce those beliefs and reinforce social order. In the western part of Burkina Faso, the role of "*Kotigi*", meaning the person responsible for water, entails leading the rituals related to water every year. The offerings made to the spirits of the water aim at the happiness of the whole village, the protection of the users against accidents in the water and the abundance of fish (Toé & Sanon, 2015). Indeed, the spirits of water have requirements and prohibitions that society must meet. On the one hand, when their will is not fulfilled they cause misfortunes, such as preventing the fish from rising to feed humans or by holding back the rain and drying up the ponds. On the other hand, when they are appeased, they can be a source of happiness. The person responsible for water, by enjoining the whole community to acknowledge and appease the water spirits, protects the rivers and ensures the respect of the rules concerning the rivers. Finally, he gives authorization of how and when collective fishing is done. The customary fishing was preceded by sacrifices made under the direction of the village chiefs or land chiefs (Tengsoba in More, Kotigi in Jula) to whom a portion of the fish returned.

Development of Commercial Fishing and Aquaculture

In 1950 the water and forest department of the national colonial administration opted for the development of fishing. This involved calling for professional fishermen from

Mali and Ghana, the so-called “bozo” and “Ashanti fishermen” to train indigenous volunteers to use new fishing techniques. The foreign fishers operated on the Black Volta and went as far as Douroula, especially at the confluence with Sourou. They introduced canoes, nets and lines (Traoré *et al*., 1994).

The colonial administration contributed also to the introduction of fish farming in Burkina Faso. In 1956 the Tropical Forestry Technical Center (CTFT) and the clergy set up the Bérégadougou fish station. The station conducted research on *Tilapia zillii* and produced fingerlings for fish production on village farms. However, after the independence of Burkina in 1960, the fish farm was abandoned (Bouda, 2002).

In 1980, the "Banfora Aquaculture Project", financed by the *Caisse Centrale de Coopération Agricole* (CCCA) used the facilities made available by the Catholic Church. This project’s success marked the first workable example of intensive fish farming in Bukina Faso. With a production estimated at 400 tonnes per year, it supplied the major urban centres of Ouagadougou, Bobo-Dioulasso and Banfora with good quality fish. However, the project ended in 1985 due to technical and financial problems (Kabré, *et al*., 2014). From 1979 to 1982, US Peace Corps personnel and a German fish project called "Misereor" financed by, Kreditanstalt für Wiederaufbau (KFW) experimented with village fish farming in the south-west of the country. Many experiments followed one another, e.g. the project on the valorization of fishing potential and fisheries management in the South-West to promote fish farming until the creation of the Ziga Aquaculture Complex, then the fish farming project of Bagré funded by the Chinese Cooperation Taiwan organization.

The construction of reservoirs increased fishery landings 15-fold since 1950, employing more than 30,000 fishermen and several thousand women for processing and selling the fish (Ouedraogo, 2010). The value of whose production is enriched by 2,300 fresh fish traders, 3,000 traders of processed fish products (e.g. smoked or dried) and 3,000 women processing fish products (MIR, 2018). Upstream of these activities are the suppliers of fishing equipment and the carpenters who make canoes and ice factories.

It is estimated that in Burkina Faso fishing can produce between 12,000 and 20,000 tonnes of fish per year depending on the intensity of the management that is done (e.g. stocking) (MIR, 2018). People in Burkina Faso have traditionally exploited the other animal (mussels, shrimp, etc.) and vegetable (water lily) aquatic food resources as well while the study into the valorization of these has only begun in recent years.

National fish production and imports have increased almost continuously since 1998 (Figure 1) while aquaculture only constitutes less than 1% (Figure 2) of total national availability reaching a maximum of 408t in 2018 (MIR, 2018). Thus, the fishermen of Burkina produced 800t in 1950, 8,500t in 2000, 15,740t in 2010, then 20,700t in 2014. From 2012 to 2016, Burkina produced on average 20,884t of fish per year. It is worth to note that the growth of capture fish production is almost exclusively associated with the creation of new reservoirs. Additionally, the implementation of several fishery development projects contributed to the training and incentivising people to engage in fishing. For instance, from 1956 to 1993 about 12 major projects devoted to capture fisheries and aquaculture were implemented in Burkina Faso (Bouda, 2002). The combination of these factors has resulted in an increase of fish production from less than 800 t in 1950 to more than 25000t per year today.

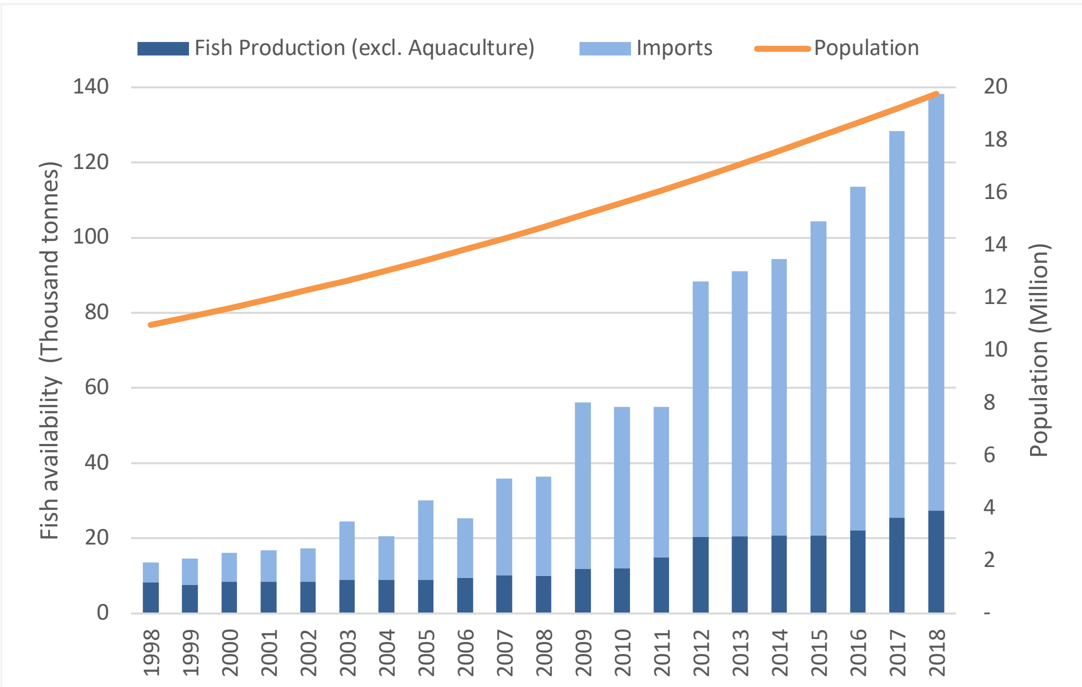


Figure 1: Fish production, fish imports (MIR, 2018) and population growth in Burkina Faso (United Nations, Department of Economic and Social Affairs, Population Division, 2019)

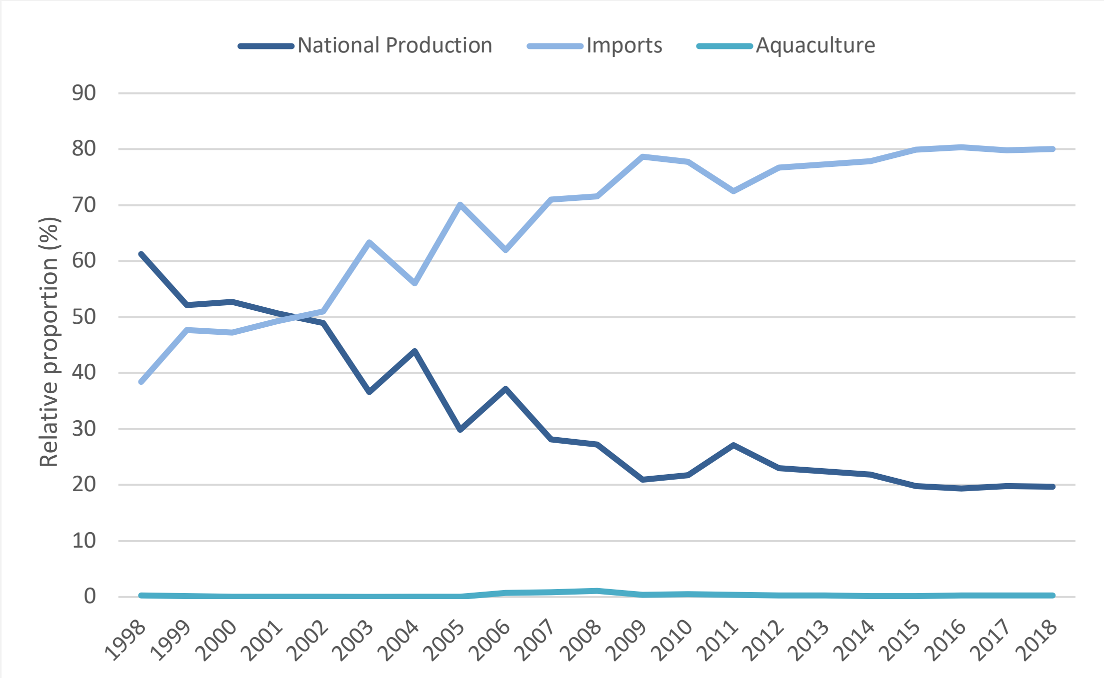


Figure 2: Relatative proportion of fish production, fish imports and aquaculture production in total fish availability (MIR, 2018)

Aquaculture is struggling to develop but substantial efforts are visible from the State and its development partners. National targets and strategies have been set in the National Adaptation Plan as well as the National Strategy for Sustainable Development for Fisheries and Aquaculture by 2025. A discussion into the history, development and potentials of aquaculture is provided in Chapter 9. Aquaculture: History and Potential) on page 88.

The most exploited species are those most abundant (see Chapter 7. Fish Sampling), namely *Oreochromis niloticus*, *Sarotherodon galileaus*, *Clarias sp*., *Schilbe sp*. etc. In addition to human consumption, some fish species are used in traditional treatment of pain and disease. This is the case of *Gymnarchus niloticus* and *Lates niloticus* (Janin, 2016), *Schilbe sp*. and *Malapterurus electricus* and many others. For instance, *Protopterus annectens* is used for the treatment of low back pain; the bones of the *Gymnarchus niloticus* vertebral column are used in the treatment of children' joint diseases (rheumatism) (Coulibaly, 2003). In 2016, in total Burkina Faso produced 20,300t of fish, 20,000 from wild fishing and 300 for aquaculture. As domestic production does not meet the demand, the country imports large quantities of fish:

80% of the 110,000 t of fish products consumed are imported (MIR, 2018). Statistics indicate that Burkina exports fish, but this is generally a re-export of imported fish.

Research on Fishing

The colonial period marked a turning point in the history of fisheries development in Burkina Faso. It was the starting point for fisheries research and the direction of activity towards a commercial fishery. Indeed, France has carried out hydrological, hydrobiological and ichthyological work in the colonies (Bouda, 2002). Key advances were made from 1959 to 1964 through Dr Benigno Roman's ichthyological research. Additionally, to his ichthyological publication in 1964, he published a "Note on the Ecology of the Dwarf Forms of Fish of Volta and Haute-Comoé", which was one of the first publications on fish ecology in Burkina Faso. Added to this are the fish and fishery monitoring carried out by the CTFT (Tropical Forestry Technical Center) between 1963 and 1967 for the development of artificial reservoirs and Daget's research on West African fishes (Bouda, 2002 and Paugy *et al*., 2011).

Fisheries research continued with a diversified field, notably through the National Center for Scientific and Technical Research (CNRST), the university, national and foreign schools and institutes, but also the many projects involved in the field of fisheries research. However, this research focused primarily on biological aspects while the socio-anthropological aspects have rarely been studied (Bouda, 2002; Toé, 1999).

Institutional Changes & Institutional Nomadism

Under the colonial administration, the forest guards oversaw the control and surveillance of the fishery based on a decree issued on July 4th, 1935 (Bouda, 2002). However, it was in September 1976 that the directorate of Fisheries and Aquaculture (DPP) was established within the Ministry of Environment and Tourism to promote the activities of the fishery sector. Thanks to funding from the Kreditanstalt für Wiederaufbau (KFW) and Misereor from 1979 to 1982 it created 28 community centres of fishermen related to the water reservoirs of Loumbila, Tapoa, Petit Balé, Nagbangré, Bazèga and Dakari by giving them nets and canoes (Traoré *et al*., 1994). Over time, the department in charge of fisheries has transferred between several ministries (Table 1).

Table 1: Change in the Ministry of Fisheries from 1960 to the present (Source: MRAH & MIR, 2018)

Ministry	Periods
Ministry of Rural development	1960-1976
Ministry of Environment	1976-2002
Ministry of Agriculture, Hydraulic and Fish Resources	2002-2011
Ministry of Environment and Sustainable Development	2011-2012
Ministry of Animal and Fish Resources	2013-2019

Until 1981, only the minimum size of the mesh of fishing tools was in force (Traoré *et al.*, 1994) at which time the first national regulation was introduced (Baijot, Ouédraogo, & Traoré, 1994; Traoré *et al.*, 1994).

In 1981, an ordinance on the organization and regulation of the fishery (Président de la Haute Volta, 1981) and its implementation decree of the same date made the waters state property, defined the different methods for granting fishing licenses, enacted measures for the protection of fish stocks, regulated the practice of fishing and lay down coercive measures in the event of infringement. This decree prohibited the use of the net, the use of any fishing gear of mesh less than 30 mm and the use of a line of unbaited hooks. The license was introduced as a prerequisite for the practice of commercial fishing.

The Forest Code, revised in 2011, (Assemblée des Députés du Peuple, 1997b; Assemblée Nationale, 2011) is currently the basic legislation that regulates fishing and aquaculture activities and sets the basic principles for the conservation, development and the management of fisheries resources. It sets in accordance with the National Forestry Policy, the fundamental principles for the conservation and protection of fisheries resources.

However, other legal instruments and international guidelines influence the management of aquatic resources among which we can mention: The Constitution of June 2nd, 1991, the Environment Code, the Agrarian and Land Reorganization (RAF), the Law of Orientation on Water Management, the Code of Conduct for Responsible Fisheries (CCPR), and to a lesser extent other codes regulating the fisheries sector.

Fishing regulations are also based on strategies, policies and plans that have also evolved over time. In 1977, the Upper Volta Fisheries and Aquaculture Development Plan was prepared by the newly created directorate. As part of the Sahel Regional Fishery Development Strategy, this plan aimed at institutional development, notably the strengthening of the DPP, the development of skills of the population, research on potentialities, then the development of fish farming. From 2003 onwards, the Strategy Paper and Priority Programs for the Development of Fisheries Resources was developed and implemented. Currently, the objectives of the fisheries and aquaculture sector are traced by:

- ✓ The National Policy for Fisheries and Aquaculture (PNPA) adopted in December 2013;
- ✓ The National Strategy for Fisheries and Aquaculture by 2025 (SNDDPA - 2025), also adopted in December 2013;
- ✓ The National Economic and Social Development Plan (PNDES), which covers the period from 2016 to 2020.

This chapter about the history of fishing in Burkina Faso is far from being exhaustive. However, it points out historically important phases in the profound transformations undergone by the fishing sector and open doors for thorough investigations on levers and factors of changes.

The social groups of Burkina have known and developed fishing practices to different degrees. However, community fishing was commonly only an occasional subsistence activity. The governance of the activity was closely linked to the access to other natural resources such as water and land. The techniques and tools used were relatively rudimentary.

Fundamental transformations of this socio-ecological system started during the colonial period, in the 1950s, when the economic dimension of fishing was put forward. An economically efficient fishing sector emerged with the development of subassembly, regulation, scientific investigation, training and aquaculture. Additionally, new institutions such as the Ministry of Fishing and a variety of regulations such as the Forest Code were created for the management of fisheries.

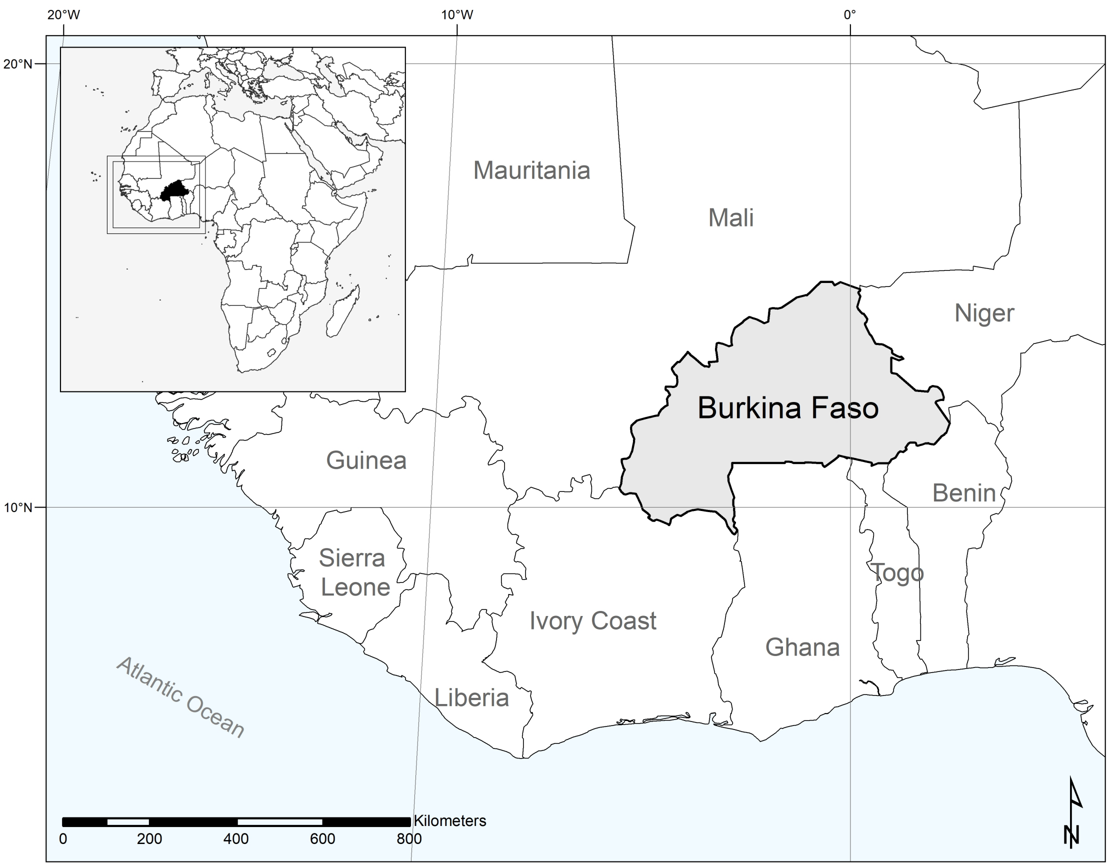
The legal instruments have been reinforced and multiplied over the years. Likewise, fishing techniques have been improved. That has strengthened state institutions to the detriment of traditional fisheries management institutions and fishing techniques to the point that often only their vestiges make it possible to reconstitute them. However, the constraints on the implementation and enforcement of the legal management considerably affect progress in the sector.

2.2. Country and Geography

Jaime Caballer Revenga, Florian Borgwardt, Julie Pailligue, Komandan Mano and Paul Meulenbroek

Geographic Zone (Burkina Faso)

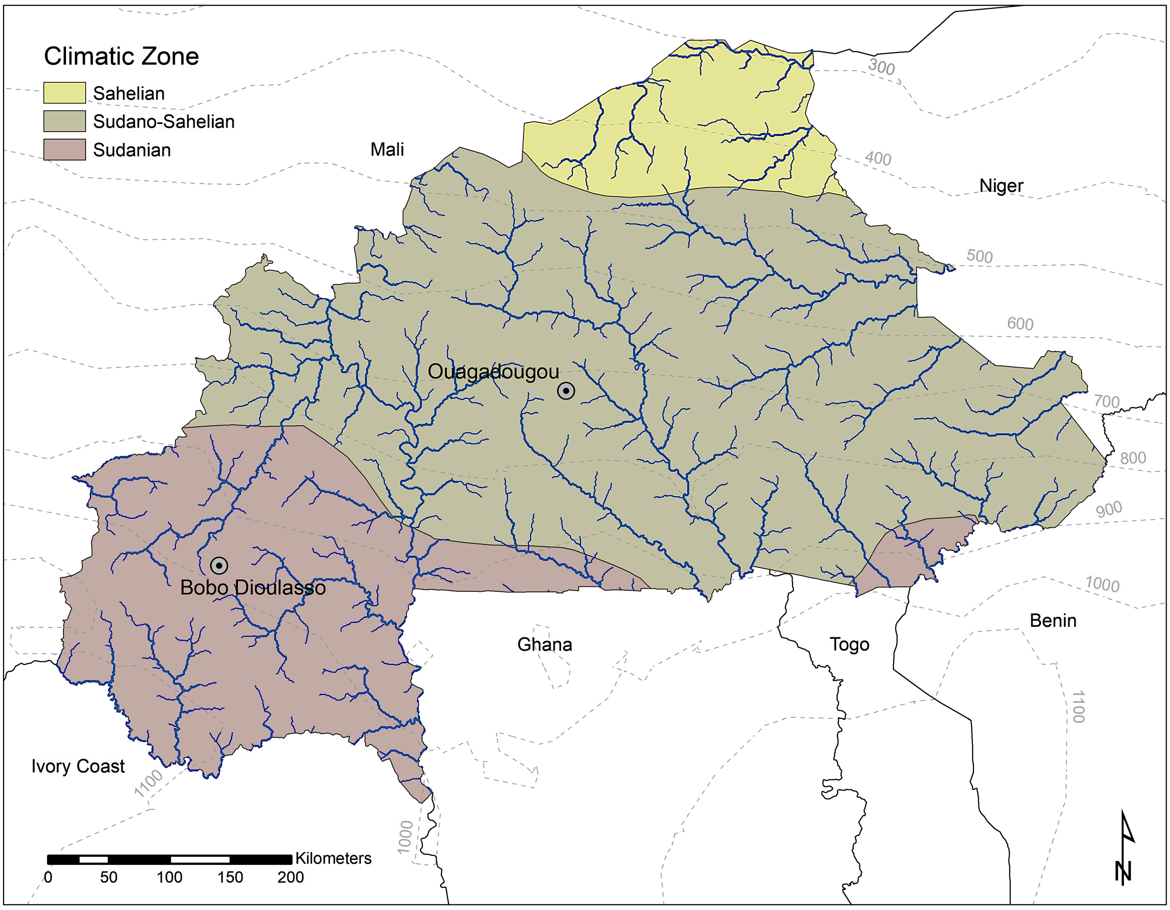
Burkina Faso is a Sub-Sahelian country in the heart of West Africa, between 9° 20' and 15° north latitudes and 5° 30' west longitude and 2° 30' east longitude. It has an area of 274,200 km^2 and an estimated population of 19.2 million in 2018 (UNDP, 2018). While it is landlocked, the country remains closely connected to the Gulf of Guinea via the large Volta River whose upper basin occupies half of its geographical area. It shares borders with six countries: Mali in the North and North-West, Côte d'Ivoire, Ghana



Map 1: Location of Burkina Faso in West Africa

and Togo in the South, Benin in the South-East, and Niger in the East and Northeast (Map 1).

Burkina Faso has a Sudano-Sahelian climate characterized by two seasons (dry season and rainy season or wintering). The rhythm of the seasons is determined by the Intertropical Front (ITF). Three main climatic zones (Map 2) characterize climate in Burkina Faso: the Sahelian zone above parallel 14° N covers about 25% of the territory with average annual rainfall between 300 and 600 mm (with the rainy season sometimes lasting less than 2 months per year), the Sudano-Sahelian zone located between the parallels 11° 30' and 14° N covers about 50% of the territory with rainfall between 600 and 900 mm (3 to 4 months of rainy season per year), and the Sudanian zone south of 11° 30' N parallel in the southwest covers about 25% of the territory with rainfall ranging between 900 and 1200 mm (4 to 6 months of rainfall per year) (Ministère de l'Environnement et du Cadre de Vie, 2007).



Map 2: Climatic zones and isohytes (mm rainfall) of Burkina Faso

Table 2: Characteristics of climatic zones in Burkina Faso (Ministère de l'Environnement et du Cadre de Vie, 2007) Translated and adapted by Julie Pailligue (2019)

Climatc zones' characteristics	Climatic zones		
	Sahelian	North-Sudanic	South-Sudanic
Geographical Location	North	Central	Southwest
Latitude	13°5'-15°3'	11°3'-13°5'	9°3'-11°3'
Average annual percipitation	< 600 mm	600-900Mm	> 900 mm
Length of the rainy season	2-3 months	3-4 months	5-6 months
Months of the rainy season	June – beginning July	May - June	End March – beginning April
Average annual temperature	29°C	28°C	27°C
Annual evapotranspiration	3,200-3,500 mm	2,600-2,900 mm	1,800-2,000 mm

Soils in Burkina Faso are characterized by their physical and chemical poverty with low clay and organic content and a very low water retention capacity leading to the formation of crusts and increased surface runoff (Rajot *et al*., 2005). Their degradation is accelerated by wind erosion, bush fires and agro-pastoral practices (intensive farming, overgrazing etc. (Doso, 2014)).

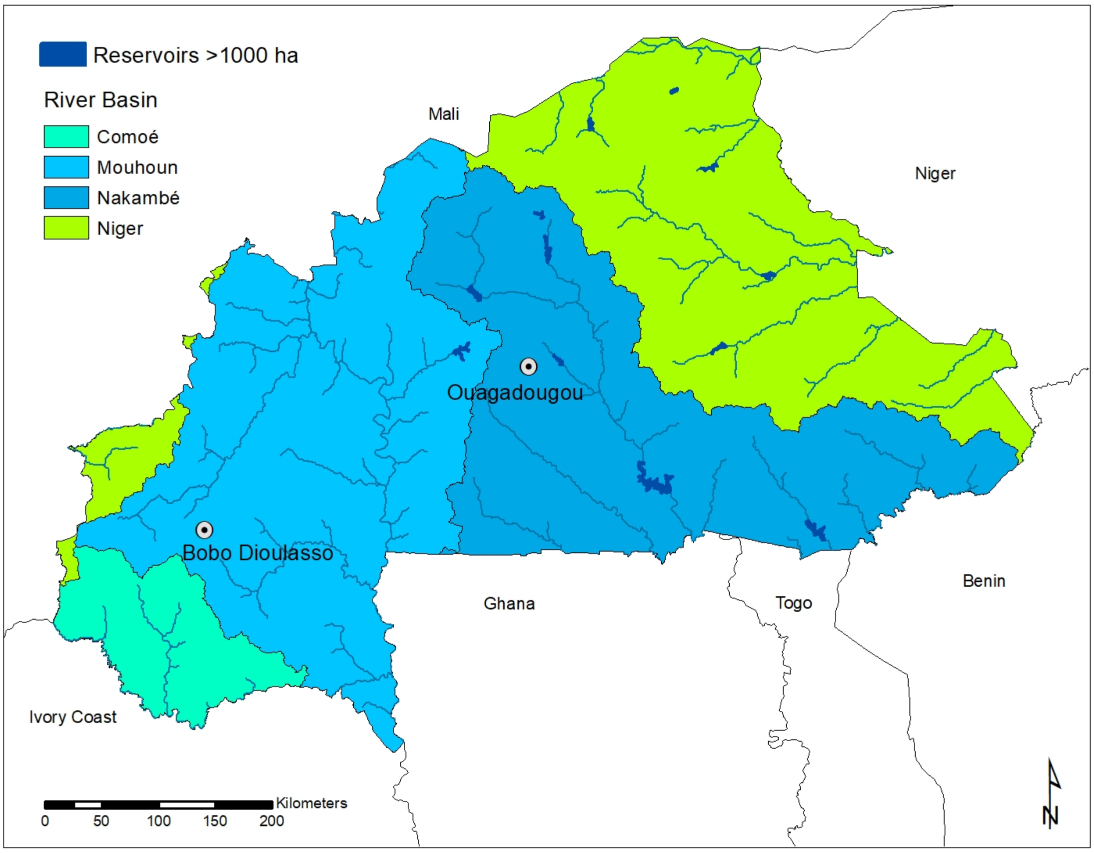
2.3. Waters in Burkina Faso

Raymond Ouedraogo, Adama Ouéda, Jaime Caballer Revenga, Florian Borgwardt, Andreas Melcher, Tristan Maurer and Soupaphone Soudachan

Lying within three large hydrographic basins (Niger, Volta and Comoé) with no major stream entering its borders, the hydrology in Burkina Faso is highly sensitive to and dependent on seasonal rainfall. Precipitation and evaporation are the main drivers determining the volume and dynamics of surface water and the replenishing of groundwater aquifers (Koussoube *et al.,* 2018).

Rivers and Streams of Burkina Faso

Four main national basins feed Burkina Faso's hydrographic network (Map 3). The Volta catchment covers 63.1% of the nation's area and provides the majority of the surface and groundwater in Burkina Faso (Gire-BF, 2001). Three major rivers, the Mouhoun, the Nakanbé, and the Nazinon (respectively Black-, White-, and Red Volta) eventually all flow into Lake Volta in Ghana (Barry *et al.,* 2005).



Map 3: Rivers, basins and large waterbodies (>1000ha) of Burkina Faso

Both the Nakambé and the Mouhoun are tributaries of the Volta and flow into Lake Volta in Ghana.

- Nakambé (former White Volta) Basin with an area of 81,932 km2 with tributaries of Sissili, Nazinon, Pendjari and Nouhao.
- the Mouhoun (former Black Volta) Basin (91,036 km2) drained by the tributaries of Mouhoun (Plandi, Kou, Voun Heu) and Sourou.

Additionally, there are the Comoé and Niger Basins.

- the Comoé Basin (17,590 km2) drained mainly by Comoé and its main tributaries (Léraba, Kodoum, Baoué and Irngou)

- The Niger Basin (83,442 km2) is drained by the tributaries of the Niger River (Banfing, Béli, Sirba, Gourouol, Gorondi and Tapoa, Diamango).

Some 5,000 km of rivers create a network that collects and distributes water flowing to neighboring countries: Côte d'Ivoire, Ghana, Mali, Benin, Togo and Niger. Only the Mouhoun and Comoé are permanent watercourses (perennial) with many smaller streams drying out in the dry season (non-perennial).

Figure 3: Rivers in Burkina Faso. Locations from left to right: Banfora, Bobo Dioulasso, Ouagadougou (Source: A. Melcher)

Waterbodies and Typology

Lentic ecosystems in Burkina Faso exist as natural and artificial bodies of water either isolated in uplands, in a matrix of different wetland types or areas of development with competing interests.

Natural bodies of water include:

- small natural pools on "bowé" armored plateaus
- mares, natural ponds or swamps
- natural lakes, such as Lac Bam or Lac Dem
- natural ponds fed by endorheic basins
- marshlands and lowlands constituting submerged wetlands in running waters: Kou and Voun Hou flood plains in the Mouhoun basin, Niéna-Dionkélé and Foulasso-Lelasso in the Bafing basin; plains of Kompienga, Mouhoun and Sourou.

Artificial bodies of water include:

- boulis, excavated waterholes used for storage of water from the rainy season or filled by seasonal water streams
- barrages or reservoirs where a dam is put in place to impound the water

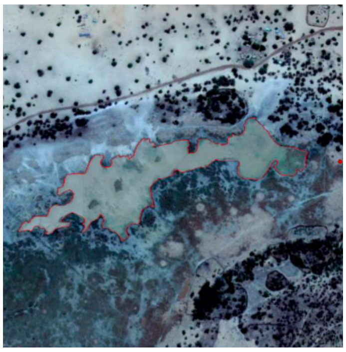
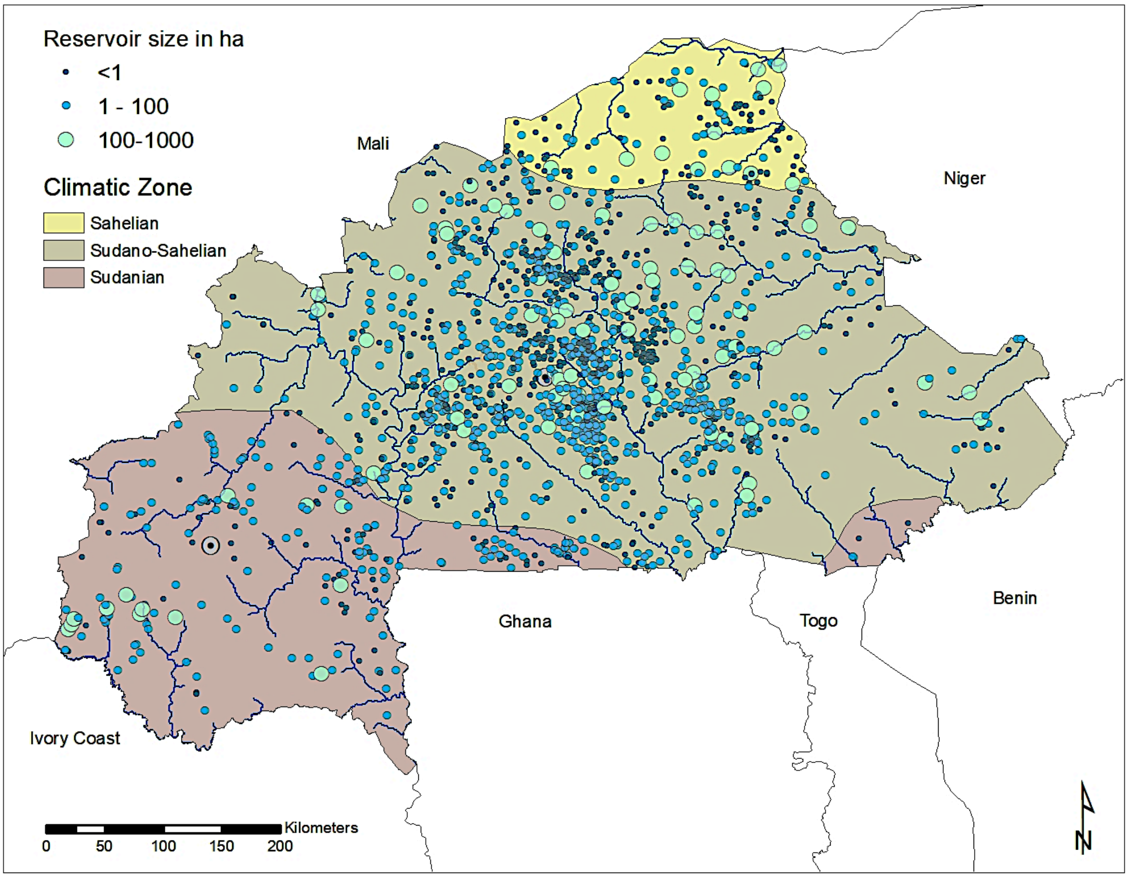


Figure 6: Mare Markoye (Maurer, 2019)

Figure 5: Bouli Gorom (Maurer, 2019)

Figure 4: Lac Dem (Maurer, 2019)

As a response to severe drought, more than 1680 Reservoirs were built across Burkina Faso (Caballer Revenga, 2019) making Burkina Faso the country with the highest density of reservoirs in West Africa (Cecci *et al.,* 2009). These range from 0.01km^2 to over 10km^2 and are scattered across the national territory and climatic zones (Map 4).



Map 4: Reservoirs distribution and size (<1-1000 ha) across Burkina Faso. Based on the results from Caballer-Revenga, 2019.

There is a concentration of small and large reservoirs around the capital Ouagadougou, yet it is difficult to decipher a pattern in the remaining territory as there is no topography favouring construction and the majority of the reservoirs are artificially constructed. Only twelve reservoirs are larger than 10 km^2, storing 51.3% of the total surface water volume endowment. The largest proportion of reservoirs lie between 0.01 and 1 km^2. A total volume of water stored in Burkinabe reservoirs was estimated at 1.46km^3 by applying a linear regression (Cecchi *et al.*, 2009). According to Boelee (2009) and Mahe *et al*. (2002), more than 50% of the annual discharge of the Nakanbé basin is held in these reservoirs by dams.

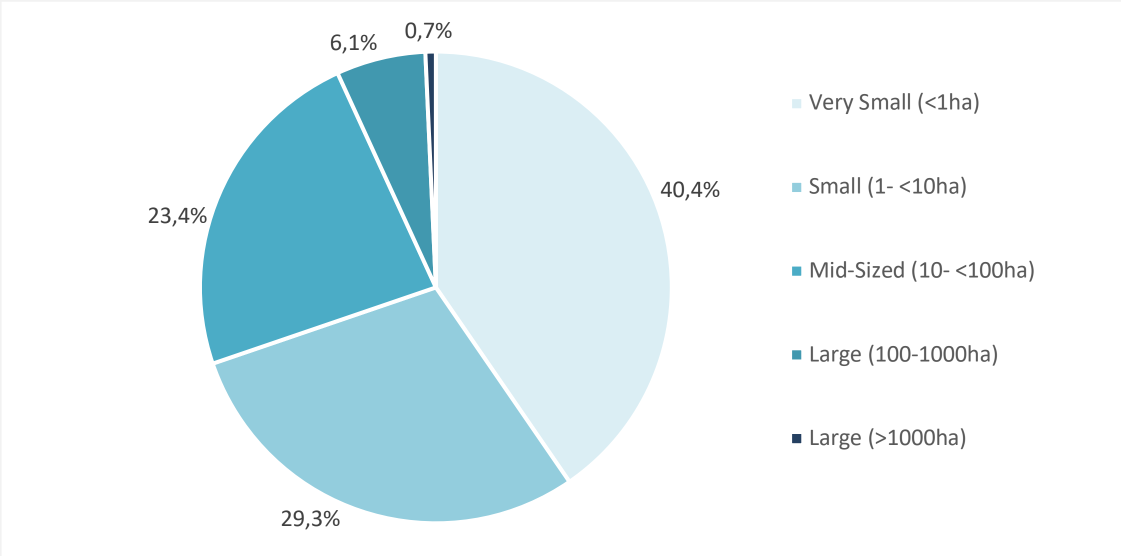


Figure 7: Relative frequency of reservoir sizes n=1680 (Caballer Revenga, 2019)

Seasonality of water bodies

Due to the dependency on annual precipitation and evaporation, the extent and shape of surface water varies with an increase (progression) in precipitation from May to September and a decrease (regression) from October to March. It is estimated that in years of drought surface waters only store about half the volume that their morphometry would allow (IWRM 2001, PANA 2006).

Groundwater reserves are estimated at about 402 billion m^3/year on average but can fall to 268 billion in a year of severe drought. The storage capacity of surface water lakes is estimated at just over 5 km^3; however, in a year of drought, these structures store only about 2.66 km^3.

Figure 8: Photos of Reservoirs varying in shape, size and intensity of use in Koubri Burkina Faso (Source: A. Melcher)

2.4. Why do we Introduce Bioindicators in African Aquatic Ecosystems?

Komandan Mano, Idrissa Kaboré, Otto Moog, Andreas Melcher and Charlotte Voigt

Development and use of Bioindicators

Water is essential for life. Despite its capacity to support complex communities of aquatic flora and fauna, water managers in Sub-Saharan countries have long focused on the quality and quantity of the water only as a fluid, not on the ecosystem services it delivers. Because water resources have been regarded as dispensable materials instead of an integral part of sustaining life, the water monitoring and assessments were based only on physicochemical parameters for a long time. However, physical and chemical analyses are time-consuming and costly (Damyanova *et al.*, 2014). Complementary approaches combining biotic, chemical and physical assessments have emerged to help assess aquatic ecosystems. Such approaches have shown that biological elements are critical for assessing and monitoring the ecological integrity of water bodies (European Commission, 2000). Biomonitoring goes beyond simply quantifying physio-chemical characteristics and can reflect the "unique signature of biological and ecosystem characteristics" of waterways (Moog *et al.,* 2018). Many programs now recommend the use of biotic elements in combination with chemical indicators to assess the ecological status of water bodies.

The development of bioindicators is more than a century old. Kolenati (1848), a citizen of the Austrian Habsburg monarchy, was the first to correctly interlink the absence of Trichoptera larvae to influences by large settlements. Hassal (1850) in London and Cohn (1853) in the old German Empire are credited to be among the first scientists to use aquatic organisms as indicators for water pollution. This led to the description of later widely used communities of aquatic ecosystems by Kolkwitz and Marsson (1902), who developed the first water quality assessment method, the "Saprobic System". This system differentiated between "saprobien" and "katharobien" organisms as indicators for organic enrichment in waters, where the former are found in wastewater and the latter in clean water. With this differentiation, the first list of indicator species was also published.

Various indices and scoring methods have been developed to quantify the ecological status of waters. These follow the principle of assigning taxa to a certain level of disturbance. In this way the impact of the disturbance or stress on a waterway can be judged by a taxa's presence or absence. There are also diversity indices which consider the species richness, relative abundance and evenness of the aquatic community. Those communities with higher diversity and a more even distribution are considered to be less stressed (Moog *et al*., 2018).

Integrative assessment systems involve the use of multiple organisms and are currently the most sophisticated approaches (Moog *et al.,* 2018). Examples of these methods are widely used in the USA (Rapid Bioassessment Protocols – RBPs), South Africa (South African Scoring System – SASS) and within the Water Framework Directive of the EU (Barbour *et al.,* 1999; Dickens and Graham, 2002; Moog *et al*., 2018). These methods include the assessment of fish and macroinvertebrates. Each group of organisms can indicate specific stresses to aquatic systems and/or deficits with regard to what is found in a healthy ecosystem at varying scales. Macroinvertebrates indicate, at a micro-habitat level, the extent of organic pollution and hydro-morphological deficits, while specific fish species can reflect deficits at a larger scale, including the reach and connectivity of the basin (Moog *et al*., 2018). For example, it was found that some taxa of EPT (*Ephemeroptera, Plecoptera* and

Trichoptera) (Kaboré *et al*., 2016a), as well as aquatic beetles of the families *Dytiscidae, Noteridae* and *Hydrophilidae* are good indicators of rivers good condition (Kaboré *et al.,* 2016d).

The term 'Biotic Integrity' was first defined in the Clean Water Act of the United States in 1972 as an "unimpaired condition or quality or state of being complete" (Watershed Science Institute, 2001). Upon this, Karr (1981) developed the Index of Biotic Integrity (IBI) combining multiple metrics to asses ecosystem health. The index uses the hypothesis that the chosen metrics react to human pressures in a predictable manner. Hence, a comparison with reference values present in pristine or natural environments gives insight into the deviation of a site from the expected 'pristine' condition.

Determining Reference Sites for Sampling

In order to determine reference sites for the biological assessment of stream and reservoir conditions, Kaboré *et al*. (2018) determined criteria for the calculation of a multiple pressure index. This helped to identify what levels of pressures and alterations an ecosystem can endure, without compromising the ecological integrity. The multiple pressure index consisted of 37 criteria (ranging from the protection status, hydro-morphological, physiochemical and sensoric features to land use and biological elements) grouped into three main types of pressure indices: hydro-morphological pressures, water quality pressures and land use pressures. The lowest intensity of pressures was found in the protected sites where all pressure indices (hydro-morphological, land use and water quality) were low. Impacted streams (e.g. Houet, Hostel Channel etc.) were found to exhibit the highest pressure index values, which were strongly linked to areas affected by human pressures. The study found some evidence of pressures in nearly all study sites, indicating a lack of truly pristine locations and making protected areas (e.g. Nazinga, Guingette, Mare Aux Hippo etc.) the most suitable for determining a benchmark level. The establishment and use of a shared assessment and monitoring system in West Africa is key in order to enable an "early warning" information system for biodiversity and conservation. For more information on pressure types in the aquatic environment of Burkina Faso and the development of indicies refer to Chapter 3 on page 28.

Macroinvertebrates as Bioindicators

Until the 1980s, works from Europe, America, Australia and recently in the developing countries have shown that biological assessment methods which use benthic macroinvertebrates for asssessment of aquatic ecosystems are the most practical (Hellawell *et al.*, 1986; Wright *et al*., 1995; Moeykens *et al.*, 2002; Kaboré, 2016a). Benthic macroinvertebrates are often chosen so as to make such assessments comparable worldwide. A range of characteristics make them particularly beneficial (Barbour *et al.,* 1999 and Moog *et al*., 2018):

- they are the most popular indicators and their use dates back to the late 1840s
- they are the major group of organisms in most waterbodies in terms of species richness and individual abundance
- their life cycles are sufficiently long that they will likely be exposed to pollution and environmental stress
- sampling the benthic macroinvertebrates assemblage is relatively simple and does not require complicated devices or great effort
- although they are mobile, they have mostly sedentary habits, so they are likely to be exposed to pollution or environmental stress
- the benthic macroinvertebrates biology are well-known and thus sufficient identification keys (mainly of European origin) and ecological databases exist as methodological standards.

Why use Fish as Bioindicators?

Fish have been widely documented as indicators of the integrity of aquatic ecosystems because of their sensibility and responsive nature to multiple impacts (Karr 1981; Karr *et al.,* 1986; Fausch *et al*., 1990). Used as bioindicators to assess the environment, fish are sensitive to short and long-term pressures including:

- land-use changes in the river catchment
- water pollution, chemical and biological toxins, acidification and eutrophication
- climate and water temperature changes

- loss of habitat and vegetation
- lateral and longitudinal migration barriers
- river morphology and riverbed alterations
- soil erosion and sedimentation
- water abstraction and other hydrological modifications
- invasive species and predators
- over-fishing and failure in fisheries management

At broarder scales a range of factors affect fish populations, including over-population, industrial influences, intensified agriculture (gardening) and hydropower. Since its introduction by Karr (1981), the original fish-based assessment (Integrity Biotic Index: IBI) has been modified and adapted for use in regions in the USA (Karr and Chu, 1999) and in other parts of the world: South America (Pinto *et al*., 2006; Pinto and Araújo., 2007; Costa and Schulz, 2010; Terra and Araújo, 2011; Casatti and Teresa, 2012; Santos and Esteves 2015), Europe (Pont *et al*., 2007; Schmutz *et al.*, 2007a; Schinegger *et al*., 2013; Breine *et al*., 2015), Asia (Ganasan and Hughes, 1998; Das and Samanta, 2006), and Africa (Hay *et al*., 1996; Hugueny *et al*., 1996; Kamdem-Toham and Teugels, 1999; Laë *et al*., 2004; Kadye, 2008; Naigaga *et al*., 2011; Aboua *et al*., 2012). Fish have proven to be one of the bioindicators best suited to reflect human pressures and impacts according to the criteria below (Karr, 1981):

- Fish are present in most surface waters.
- The catch and identification of fish is relatively easy, and their taxonomy, ecological requirements and life histories are generally better known than other biota (e.g. benthic macroinvertebrates, phytoplankton, algae).
- Fish respond strongly to changes among hydrological and environmental flow patterns, while other biological elements hardly indicate these impacts.
- Fish have evolved complex migration patterns, making them sensitive to continuum interruptions.
- The longevity of many fish species enables assessments to take a sensitive approach to disturbance over relatively long time scales.
- The natural history and sensitivity to disturbances are well documented for many fish species and their responses to environmental stressors are often known.

- Fish generally occupy high trophic levels and thus integrate conditions of lower trophic levels. In addition, different fish species represent distinct trophic levels, e.g. omnivores, herbivores, insectivores, planktivores and piscivores.
- Fish occupy a variety of habitats in rivers: benthic, pelagic, rheophilic, limnophilic, etc. Species have specific habitat requirements, and hence exhibit predictable responses to human-induced habitat alterations.
- Decreased growth and recruitment are easily assessed and reflect stress.
- Fish are valuable economic resources and are of public concern. Using fish as indicators confers an easy and intuitive understanding of cause-effect relationships on environmental impacts to stakeholders beyond the scientific community (McCormick *et al*., 2000).

Hugueny *et al*. (1996) noted, already 20 years ago, that fish must become a well-established indicator to support better management that secures an important source of food (protein), especially for Burkina Faso and other less developed countries.

3. Threats to Aquatic Ecosystems in Burkina Faso

Adama Ouéda, Idrisse Kaboré, Raymond Ouedraogo, Moumini Savadogo, Paul Meulenbroek, Sebatian Stranzl, Jan Sendzimir, Komandan Mano and Charlotte Voigt

3.1. Pressure Types

Despite the natural aquatic riches in Burkina Faso and the importance of these riches to its inhabitants, the country's wetlands are threatened by several factors, including human activities, pollution, land use, habitat loss, and overexploitation of resources. Additionally, climate change, which in some of the most likely scenarios will lead to a warmer and drier climate but with extreme rain events, will also tend to exacerbate the loss of habitats and species.

The potential for these pressures to expand and precipitate irreversible degradation of aquatic ecosystems is a strong mandate for establishing a system to assess and monitor ecosystem quality (Kaboré *et al*., 2018, Meulenbroek *et al*.,2019).

Figure 9: Pictures of pressures on aquatic ecosystems found in Burkina Faso Livestock (1), eutrophication (2), fishing (3), water abstraction (4), vegetable farming (5), barrier (6), rice farming (7), habitat modification (8) and agriculture (9) (Mano, 2016)

- **Changes to stream morphology** are often a consequence of human activities in the watershed. These include hydropower generation, flood protection infrastructure, navigation, water extraction for irrigation, soil drainage, urban development and sand extraction. Mechanical actions such as flushing of rivers, the channelling of embankments with riprap or concrete influence the functioning of the aquatic environment and modify the dynamics of the rivers. They impact flow velocity, sediment transport and biological habitats, disturbing the biotope structure, and hence the resident organisms. The cleaning of a watercourse usually follows hydraulic considerations. For example, siltation and clutter of the riverbed can impede water flow, and the resultant flooding can cause the managers to perform such cleaning. The primary causes are generally at another level upstream: urban planning, sediment erosion accelerated by deforestation, ditch elimination or poor drainage.

Figure 10: example of channelisation in Burkina Faso (Source: Idrissa Kaboré)

- **Hydrological pressures,** such as changes in the water flow through extraction or constructions (e.g. dam, reservoir or diversions) can modify the water regime during the hydrological year. Withdrawals that are large in relation to the quantities available and / or are carried out during periods of low water, can disrupt the water cycle and upset the equilibrium of the ecosystem. Such withdrawals are driven by water extraction for irrigation, industrial or other human uses. Hot water discharges (e.g. industrial discharges), if they are regular, can also generate changes in the ecosystem by changing the species composition.

Figure 11: The pumping of water out of reservoirs for agricultural use (Source: A. Melcher)

Figure 12: Irrigation on agricultural fields (Source: A. Melcher)

- **Habitat pressures:** The use of the land surrounding aquatic ecosystems influences chemical and sediment inputs. Expansion of intensive agricultural or urban areas due to rapid population growth and increased irrigation possibilities can restrict or remove the riparian vegetation that filters surface runoff, among other ecosystem functions.
- **Riparian land-use pressures**: Expansion of agricultural area or deforestation in the riparian zone can lead to increased siltation and run off, as well as reducing the habitat diversity for aquatic animals (Kaboré *et al*., 2018).
- **Connectivity pressures,** such as barriers created by dams or the sealing of the riverbed, will reduce ecosystem connectivity, preventing material and nutrient transport as well as the movement of aquatic fauna.
    - **Barriers to fish migration** is an issue in Burkinabe waterways as many of them are non-perennial (dried out during the dry season) or disrupted through damming. Assessment of fish assemblages by Melcher *et al*. (2012) showed that while dams present a barrier for fish, leading to reduced abundance of larger species intolerant of habitat degradation, frequent dam breaks and flooding as a part of dam management can also enable movement and exchange of fish between sections of the river.
- **Water quality pressures:** In Burkina Faso, human water utilization in and near the water, e.g. fisheries, agriculture or human settlements, impair water quality. Domestic discharges (untreated wastewater), untreated discharges from certain industries, and agriculture through livestock farming, pesticides, silage and the

application of manure/sludge are major sources of pollution. Excessive use of fertilizer can have a similar effect through erosion or leaching. The increased supply of organic matter and nutrients to the aquatic environment can lead to eutrophication promoting algal blooms, thereby consuming massive amounts of oxygen thus killing fish and other aquatic biota. Three main groups of micropollutants from human sources are generally identified: organic, metallic and organometallic pollutants. These are generated through the exploitation, transformation, use and degradation of raw materials. Depending on their physicochemical and toxic characteristics, they will impact all or part of the ecosystem to some degree. Either inhaling or skin contact at work or through food consumption can expose humans to these pollutants. Special notice should also be given to bacterial and phytochemical pollution in Burkina Faso.

- **Bacterial pollution:** Water bodies are often contaminated with faecal coliform and streptococcal bacteria due to untreated human and animal waste (Yonkeu, 2002). This is a proxi for disease (Boelee *et al*., 2009) and can result in reduced growth and stunting in children (Ngure, 2019).
- **Phytochemical pollution:** Due to growing fruit and vegetable production as an alternative to cash crops during the dry season, the use of pesticides to improve yields has also increased. Gardening areas in Burkina Faso are located close to waterbodies. This proximity results in high levels of run-off, permeation through soil and spillage directly into the waterbody. Studies by Lehmann *et al.* (2018) found in total 13 different pesticides present in drinking-water sources in Burkina Faso, the most prevalent being Triazine, Acetamiprid, and Imidacloprid. Pesticides can have negative impacts on human health by disrupting the endocrine system (WHO and UNEP, 2013) as well as damaging aquatic communities as examined on zooplankton species by Leboulanger *et al.* (2009).

Figure 13: Examples of polluted waterways due to urban waste (Source: Ouédraogo et al.*, 2012)*

- **Changes in biocenosis, invasive alien species**: In an aquatic ecosystem, all living species or the biocenosis interdependently operate in a balance across the food chain and the productivity pyramid. The disappearance of one or more species or the introduction of an invasive alien species can disrupt and break this balance. The disappearance of species can be due to overfishing, invasive species such as *Lates niloticus* (Lowe *et al.,* 2000) or other disruption of the aquatic ecosystem.
- **Climate change**: Although the impact of climate change on wetlands is far from being fully understood, it is expected that increased climate variability will further stretch the resilience of aquatic ecosystems by changing the dynamics and extent of water flows and storages. Such extremes will accelerate habitat degradation and species loss (See Chapter 4: Climate change impacts on page 36).

Figure 14: Broken dam of Koubri after heavy rainfall August 2017 (Source: R. Ouédraogo)

3.2. Using Indicies to Summarize Pressures

In order to quantify and compare the extent of pressures at different sites, indicies can be calculated for each pressure type individually and compiled into a global pressure index (GPI). In the method developed by Schinegger *et al.* (2012), pressure variables such as impoundment, channelization, organic pollution and barriers are defined and grouped into pressure groups (hydrological, morphological, water quality and connectivity). For each pressure variable, classes from 1-5 are assigned to indicate the presence and extent of the variable. The index value is calculated as the average of the pressure variables. In order to prevent low pressure values for compensating high pressure values, the average of the high pressure values is calculated. The GPI can then be determined by calculating the average of all pressure type indicies, multiplied with the number of pressure groups displaying a high pressure value (Schinegger *et al.* 2012).

$$GPI = \frac{HPI + MPI + WQPI + CPI}{4} \times affected\ groups$$

The GPI is a helpful tool to demonstrate the cumulative effects of pressures on aquatic ecosystems. Effects often combine and multiply making an understanding of the interactions and hierarchies necessary for effective management (Schinegger *et al.* 2012).

Using this methodology, Meulenbroek *et al.* (2019) summarized the pressures on aquatic ecosystems in the Upper Volta Basin. The cumulative sum of the pressure indicies gives an indication of the pressure intensity in each study area (Figure 15). The highest hydrological pressure index was found in Bagré amplified by the proximity to large reservoirs. The lowest hydrological pressure was found in the protected area Nazinga. Here, the water quality was also the best, indicating low levels of eutrophication and pollution. The connectivity of the river was least impeded in the free-flowing section of Kougri and in Bagré, while the Koubri area contained dams in the segment, and hence received a bad connectivity pressure index. Except for the protected area of Nazinga, the agricultural and fishing pressures were high in all sampling areas.

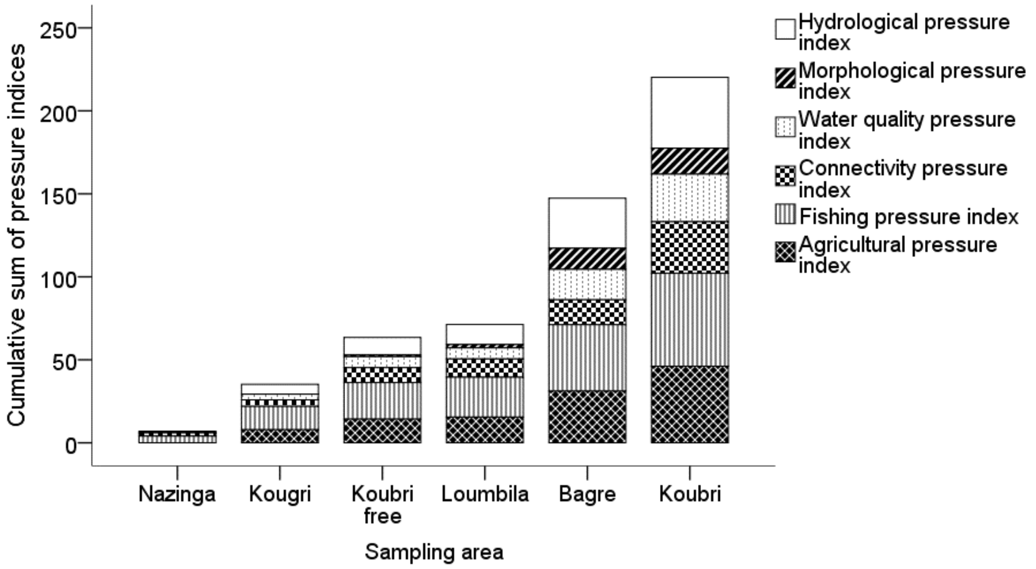


Figure 15: Pressure indicies and cumulative sum for the sampling sites (Meulenbroek et al., 2019)

Studying the impacts of pressures on fish species diversity, Stranzl (2014) found that there is a clear reaction of the fish population to the extent of pressures. A significant difference in the number of species was found between the low, medium and high GPI values. While sites with a low GPI value (4) had the highest median number of species and the highest variation, sites with a high GPI (12), had a lower number of species per site and also a lower variation between the sites (Figure 16 a). The total biomass was also found to decrease with increasing pressure (b). The abundance of multiple genera was found to significantly correlate with the pressure indicies. Especially the genera *Auchenoglanis, Ctenopoma* and *Hydrocynus* were found to be negatively correlated with most of the pressure type indicies while *Tilapia* was found to have a positive correlation (Stranzl, 2014).

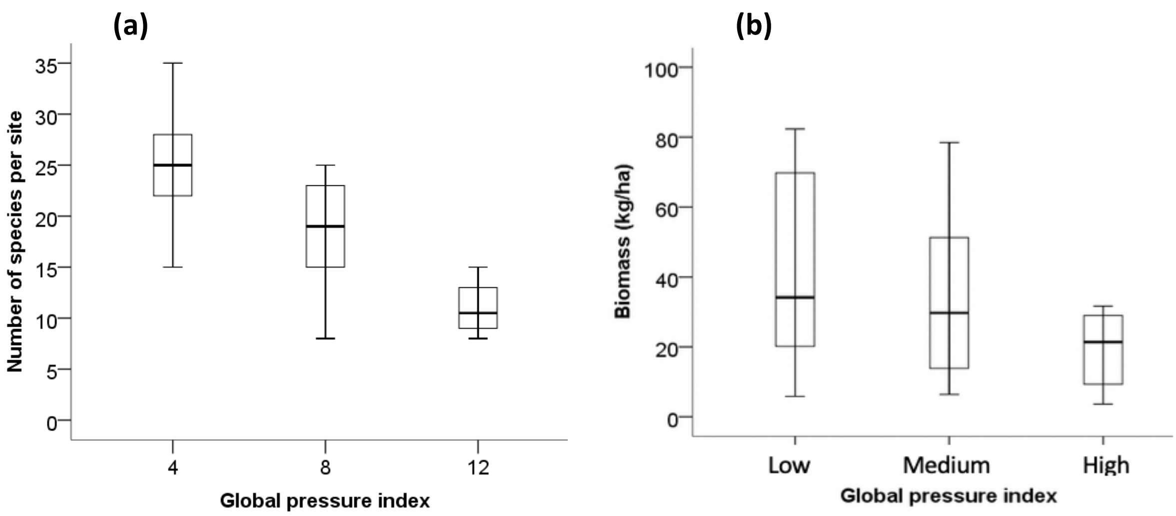


Figure 16: Relation of (a) number of species per site and (b) biomass in kg/ha with the Global Pressure Index (low GPI: 4, medium GPI: 8, high GPI: 12) (Stranzl, 2014)

Kaboré *et al.* (2016) examined the functional and taxonomic composition of macroinvertebrates at 29 different sites with different disturbance levels in the surrounding floodplain [protected area (P), extensive agriculture (EA), intensive agriculture (IA) and urban (U)]. Using a multimetric approach; taxa richness (a), percentage of tolerant dipteran insects (b), percentage of *Ephemeroptera*, *Plecoptera* and *Trichoptera* (EPT) (c), and the Shanon-Wiener-Diversity Index (d) were calculated as indications of ecosystem health. It was found that while the metrics had a different level of sensitivity to changes in land use pressures, all were able to detect a significant difference to urban areas, which had the highest level of human pressure (Kaboré *et al.*, 2016).

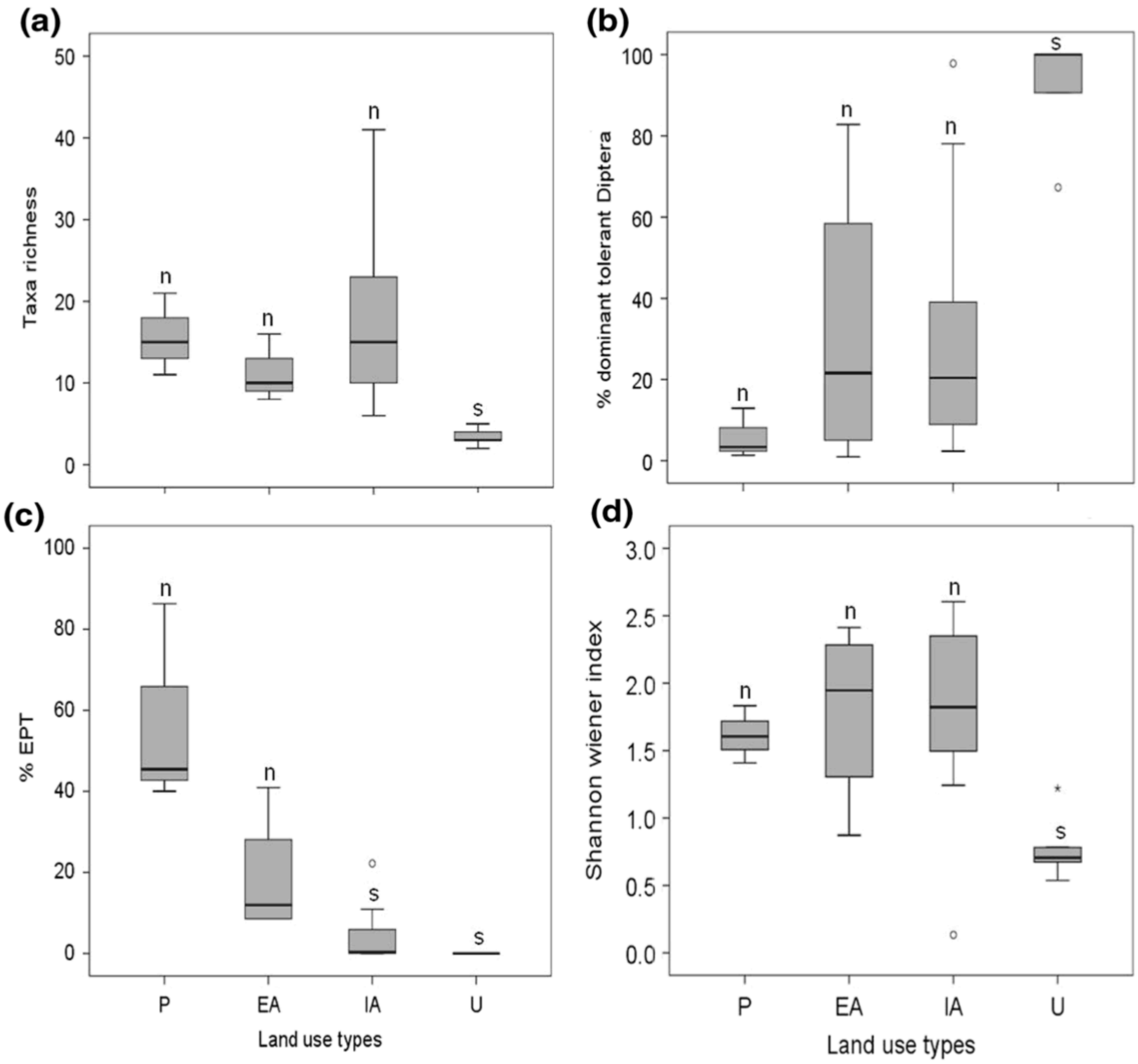


Figure 17: Variations of (a) taxa richness, (b) percentage of dominant tolerant Diptera, (c) percentage EPT, (d) Shannon Wiener Diversity Index in different land use types. P: Protected Areas, EA: Extensive Agriculture, IA: Intensive Agriculture, U: Urban areas. Letters above the boxplot indicate statistical difference in the respective plots (n: no significance, s: significance) (Kaboré et al., 2016).

4. Climate Change Impacts on Fish Resources

Julie Paillaugue, Rimwaodo Pierre Silga, Noellie W. Kpoda and Adama Ouéda

4.1. Climate Change Impacts on Biotic Factors

West Africa is one of the regions most vulnerable to climate change in the world due to its high dependency on natural resources and rainfed agriculture (Caminade and Terray, 2010; Reinert *et al*., 2015). Repeated droughts and floods, epidemics and political instability challenge food security for more than 20 million people and about 6 million malnourished children (USAID, 2017). Climate change compounds these on-going vulnerabilities. Additionally, strong population growth drives mounting pressures on natural resources (including water and fish) and causes deforestation, depletion of vegetation (through agricultural expansion and overgrazing) and resettlement of population into floodplains, creating self-reinforcing feedback loops. Burkina Faso is divided into three climatic zones; Sahelian, Soudano-Sahelian and Soudano-Guinean climatic zones (Map 2 on page 15). This results in a climate ranging from arid to semi-arid in the northern two-thirds of the country, to subtropical in the South West (Beck *et al*., 2018). Rainy and dry seasons affect the country's defined-climatic zones at different times and durations. The rainy season starts earlier and lasts longer in the Soudano-Guinean zone (i.e. March; 5-6 months) and starts later and lasts a shorter time in the Sahelian zone (i.e. June; 2-3 months) (Ministère de l'Environnement et du Cadre de Vie, 2007).

According to the Ministry of the Environment and Fish Resources (2015) and several researchers (Paeth *et al*., 2011; Nicholson, 2013; Lavaysse *et al*., 2016; Ndehedehe *et al*., 2018), climatic factors have been greatly modified recently in the Sahel region and especially in Burkina Faso (i.e. precipitation patterns, air and water temperatures, winds, extreme events occurrence). Following a literature review by Paillaugue (2019), several meteorological pressures on the abiotic conditions of waterbodies were identified as likely arising from climate change and impacting further some biotic characteristics of local aquatic ecosystems (Table 3 and Table 4)

Table 3: Major climatic factors shown as adversely modified by climate change and the consequent influences on waterbodies' abiotic state based on literature review by Paillaugue (2019)

Climatic Factors	Water Abiotic Factors
Precipitation – increase in variability, decrease of total annual precipitation	**Floodplains** – reduction in area flooded, reduced duration of flooding
	Water Flow – reduced stream flow, increased seasonality of streams, decreased water level and availability, reduced connectivity of water bodies, drying out of streams lakes and reservoirs
	Runoff – decreased runoff from precipitation
Solar radiation – increase in intensity	Indirect effects through surface temperature and convection
Air Temperature – increase in mean annual temperature, increase in night temperature and increase in minimum mean temperature	**Water Bodies** – increase in surface water temperature, increase in stratification, increased salinity due to increased evaporation, decrease in dissolved oxygen content, increase in eutrophication and harmful algal blooms
Evaporation – increased evaporation	**Floodplains** – reduction in area flooded, reduced duration of flooding Habitats – reduced quality and quantity, decrease in size
Extreme Events – increased frequency of floods, increased intensity and reduced duration	**Floodplains** – reduction in area flooded, reduced duration of flooding **Droughts** – increase in surface water temperature, increase stratification, increased salinity, decrease in dissolved oxygen content, increase in eutrophication
Seasons – change in timing, duration and intensity of rainy season, increased duration of dry season	Indirect effects on precipitation

A decrease in the annual mean precipitation, an increase in annual mean temperature and increase in precipitation variability were mentioned most frequently in the literature as pressures resulting from climatic change.

A decrease in water availability, increased surface water temperature and decrease of floodplains' area flooded and decrease in runoff and water flow were recognized as the abiotic indicators mainly modified by the latter climatic pressures. The resulting impacts on biotic indicators related to fish can be seen in Table 4.

Table 4: Water abiotic factors indirectly affected by climate change and the resulting impacts on fish biotic states based on literature review by Paillaugue, (2019).

Water Abiotic Factors	Fish Biotic States
Floodplains – reduction in area flooded, reduced duration of flooding	Reduced **fish average size**
	Reproduction – decreased rate, change in time of spawning, hindered migration, decreased recruitment
	Reduced **fish abundance**
Water flow – reduced stream flow, increased seasonality of streams	Increased **fish mortality**
Water level – decreased level and availability, reduced connectivity of water bodies, drying out of streams lakes and reservoirs	Increased **species extinction**
	Reduced **fish average size**
	Reduced **productivity**
	Reduced **primary production**, reduced **distribution**
	Decrease in **fish abundance**
Dissolved oxygen content – decrease	Decrease in **fish average size**
Surface water temperature – increase	Reduced **primary production**
	Decrease in **fish average size**
Salinity – increase	Reduced **primary production**, reduced fish species **distribution**

Figure 18: Floodplain largely deserted next to the reservoir of Koubri, which used to host local population and an important fish market (Source: P. Magnuszewski)

The major biotic factors identified in literature as adversely affected by climate change impacts were a reduction in fish abundance, productivity, average size and a decrease of the primary production due to rising water temperature and salinity (e.g. Mohammed, 2013; Harrod, 2015; Paugy, 2017; Yang, 2017 and Issahaku, 2018). Complimentary interviews (Paillaugue, 2019) showed a lack of information dissemination within the country, regarding climate change process and impacts, limiting fisheries' stakeholders' perception of current and potential future threats on fish resources. Moreover, Ficke, Myrick and Hansen (2007) highlighted that climate change impacts can be easily underestimated, hidden or impeded by direct anthropogenic pressures (e.g. overexploitation, deforestation, land-use changes) especially overwhelming in developing countries. This may also hinder the understanding of main fishing actors regarding the origins of biotic changes, impeding the adoption and implementation of effective adaptation strategies to sustain fisheries.

Figure 19: Interview of a participant about climate change impacts on water and fish resources in Burkina Faso (Source: A., Melcher, 2019)

4.2. Endogenous Knowledge and Perceptions of Fishermen on Climate Change

Case Study of the Bagré Lake Fishery

Global warming and its repercussions on natural resources, although accepted today by a large number of scientists, still remains a source of sometimes divergent discussion among local populations. A study carried out between March and June by Rimwaodo Pierre Silga and his colleagues within SUSFISH+ used semi-structured group surveys among local populations around the Bagré Lake in the North-Sudanian zone of Burkina Faso. The objective was to assess the perception of local changes by fishermen and their impacts on the ichthyofauna. A total of 118 fishermen from 7 surrounding villages in 20 groups took part in the interviews.

The results showed that fishermen are generally aware of climatic and anthropogenic threats to fish fauna with agriculture, gardening and climate change as the most cited stressors (Figure 20). There is also growing awareness of the decreased water levels in the lakes, silting, agriculture and opening of lake dikes are seen by the fishermen as the main drivers of this change (Figure 21).

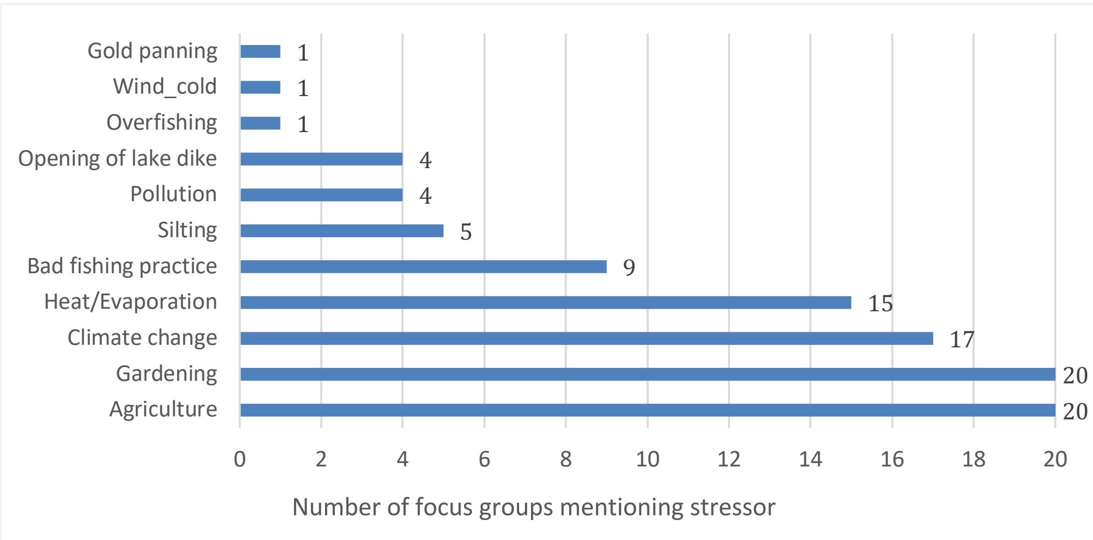


Figure 20: Perception of stressors on fish fauna by fishermen (Source: Silga et al., in preparation)

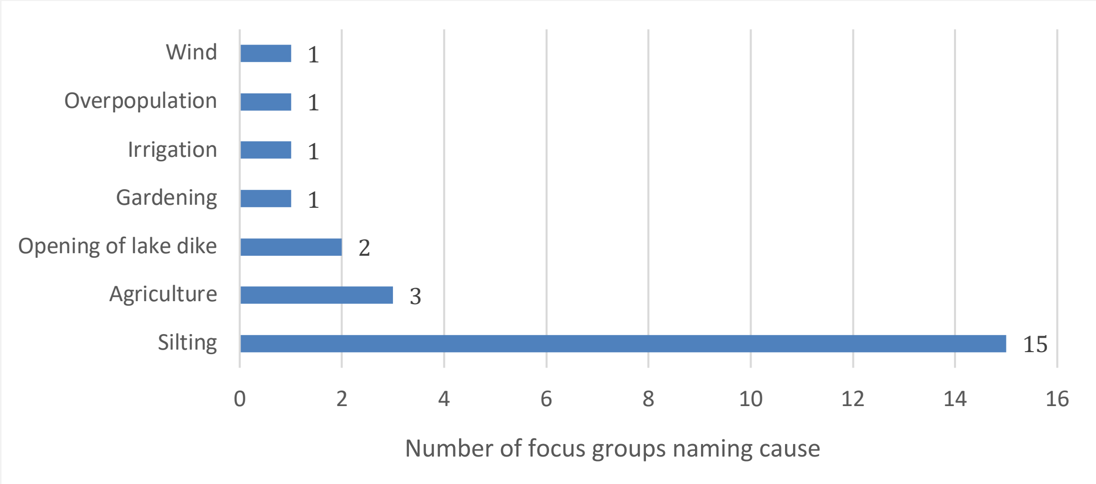


Figure 21: Named causes of water level decrease in lakes (Source: Silga et al., in preparation)

The fishermen have also noted a decrease in the quantity and quality of fish caught due to different stresses. According to them, climatic changes are the basis of significant changes in fish communities ranging from habitat loss to a decrease in species richness. According to the fishermen, some fish are dying in specific periods of year (Figure 22). This increase of fish mortality could be explained through pollution and increased temperatures. Several fish species are even perceived to be endangered (Figure 23). This endogenous knowledge is important for the development of climate change adaptation programs. The data collected confirms the research hypothesis that fishermen are aware of pressures on the fish fauna of Bagré Lake and draw conclusions about the natural and anthropogenic causes.

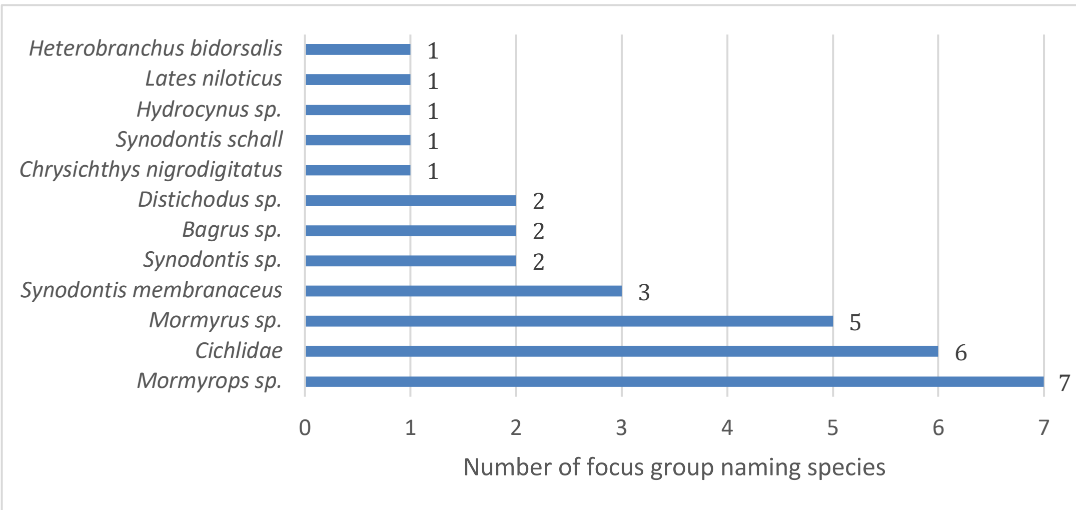


Figure 22: Species and Genera perceived dying in certain periods of the year (Silga et al., in preparation)

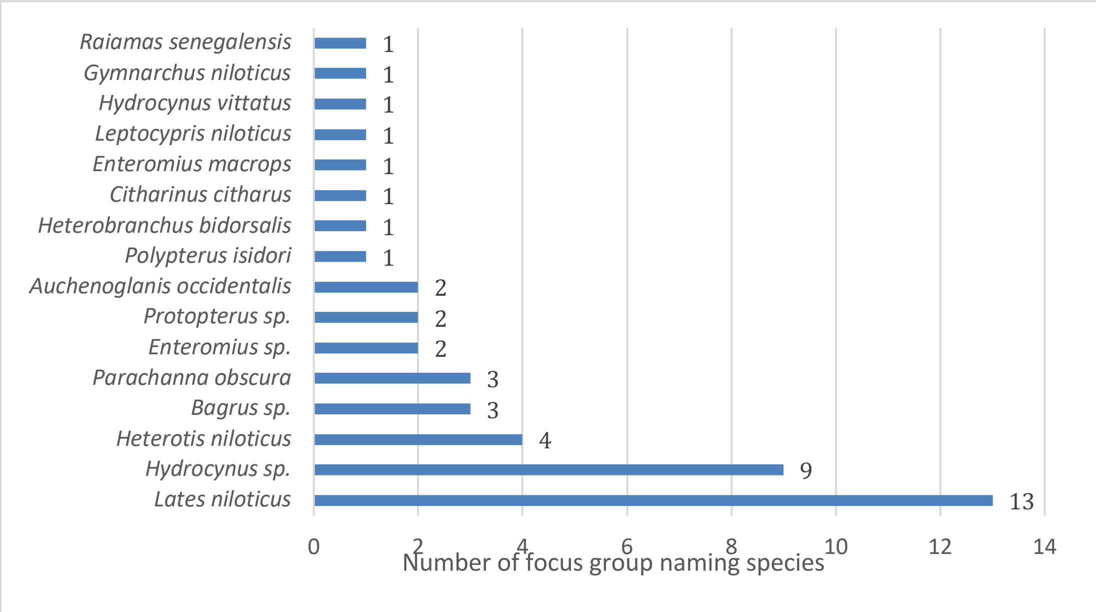


Figure 23: Fish species named by fishermen to be endangered (Source: Silga et al., in preparation)

4.3 Modelling Impacts on Fish Distribution

To assess the impact of climate change on fish species distribution in Burkina Faso, a modelling analysis was completed. Data used was based on studies of fish in Burkina Faso over the period 1951 to 2010. For evaluating the impacts of climate change, the period was subdivided into three sub-periods at regular intervals of two decades. The reference period refers to 1951-1970, before widespread drought in the Sahelian area, the critical period refers to the years of drought from 1971-1990 and the coming back period, also considered the current period, reflects the years since the drought. Nineteen variables, from Worldclim version 1.4 and version 2.0, expressing climatic data derived from temperature, rainfall and seasonality were used to model the fish distribution during these periods. Fish distribution maps were established using MAXENT 3.4.0 and R 3.6.1. The study covered all reservoirs of Burkina Faso where fish species were found in the defined period (1951 to 2010).

A sample of eight fish species whose occurrence over each climatic period is greater than or equal to 10 individuals were used for this modelling. The trend of geographic occupation has been decreasing for all eight species since the critical period as seen in Figure 24 and Figure 25 where the green area indicates a higher probability of occurance. However, some fish species such as *Labeo coubie*, *Marcusenius senegalensis*, *Polypterus senegalus* and *Synodontis schall* experience an increase in their geographical area between the reference period and the critical period Figure 24 a, c and Figure 25 e, f. The Sahelian region, namely the Niger Basin has a very low occurrence for all species. This could be explained by the scarcity of rainfall, the low abundance of water reservoirs compared to other basins and the small amount of scientific research conducted about fish in this part of the country.

Fish are very sensitive to temperature and rainfall variation making them especially vulnerable to fluctuation of climatic variables. As climate change progresses, the spatial distribution of fish will change as a result; studying these distribution changes could have important implications in terms of ecosystem monitoring. For future work, further examinations into the impacts of other environmental pressures such as human activities or land use on fish populations should be conducted.

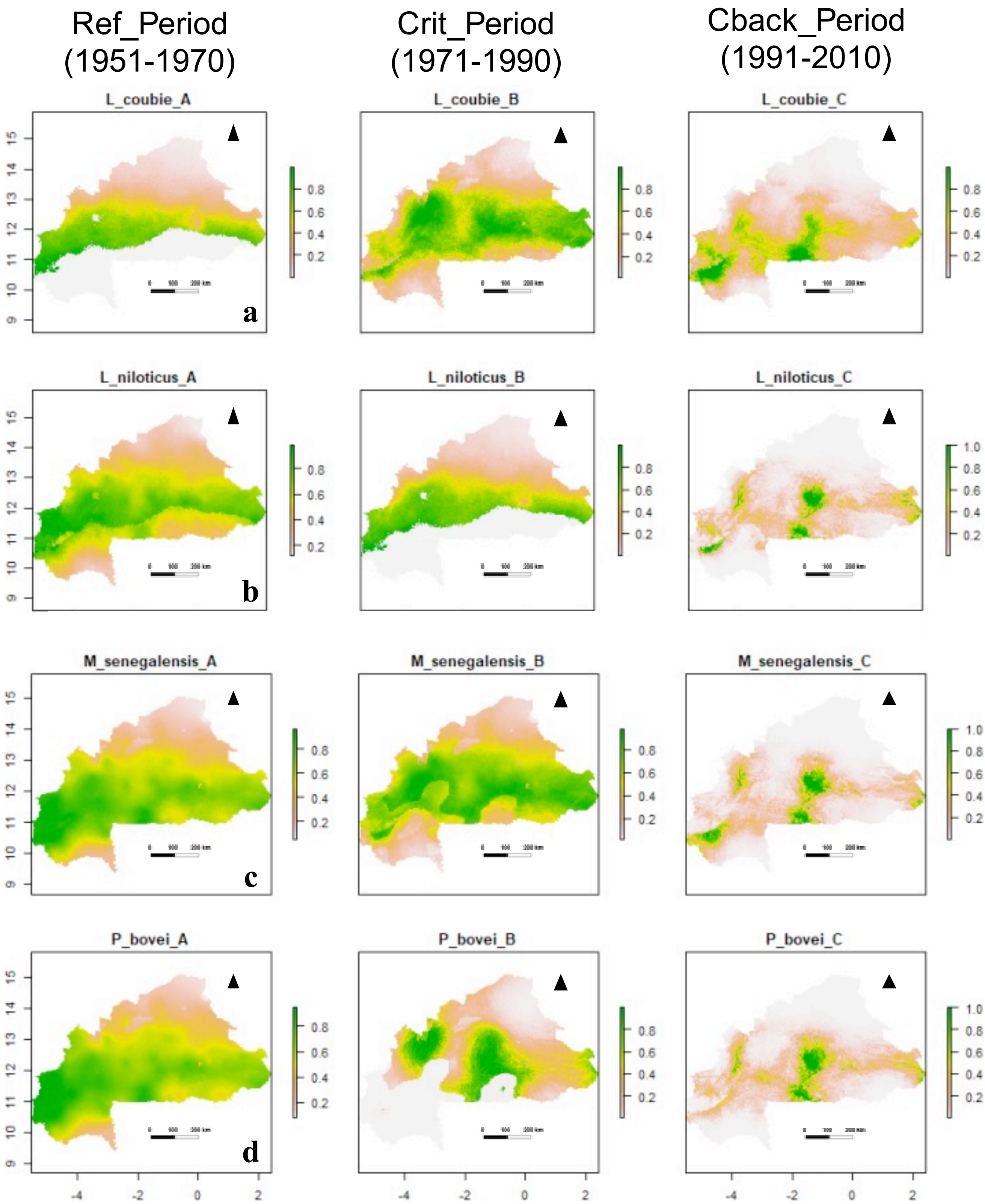


Figure 24: Occurrences and past simulations of Maxent models shown for selected species. Scale bars show Maxent logistic output, higher values (green color) indicate higher probability of fish occurrence and low values indicate low probability of fish occurrence (Source: Silga et al., in preparation)

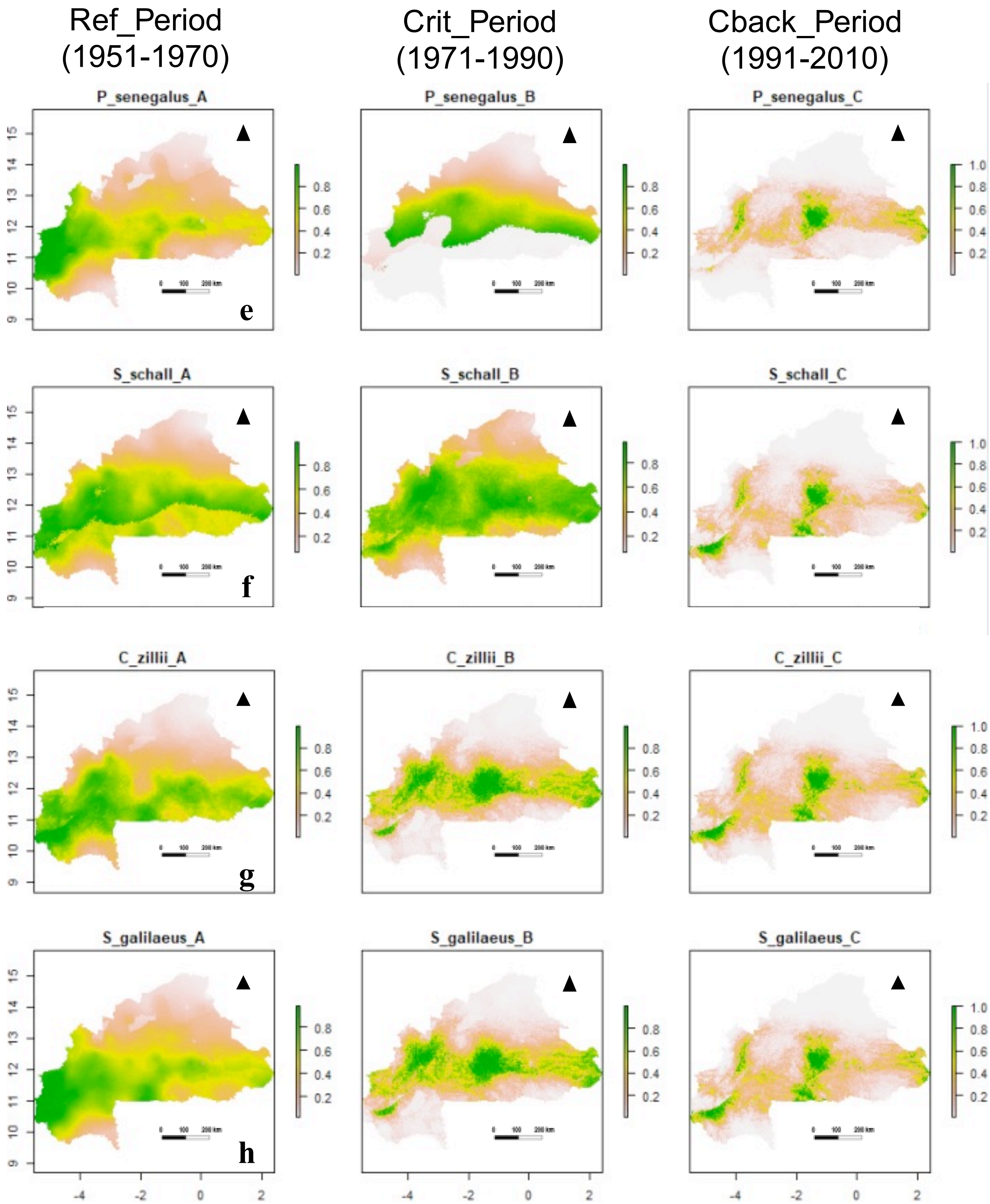


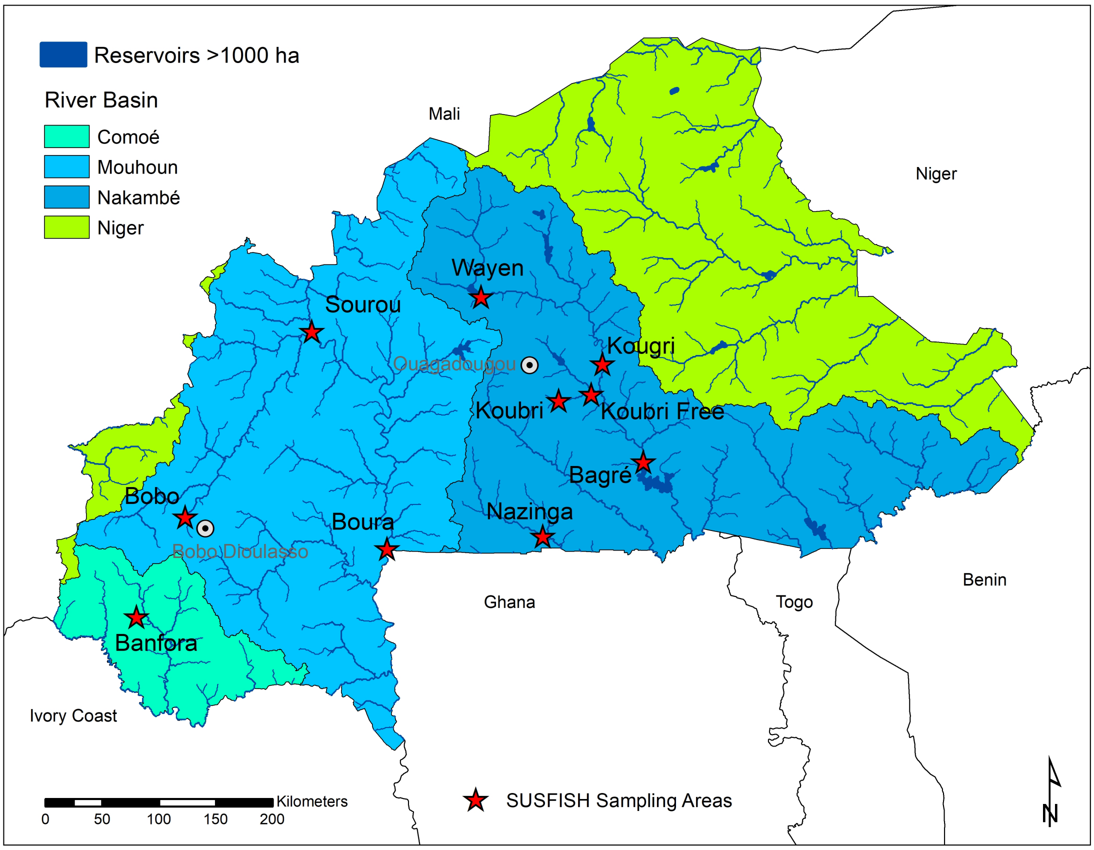
Figure 25: Occurrences and past simulations of Maxent models shown for selected species. Scale bars show Maxent logistic output, higher values (green color) indicate higher probability of fish occurrence and low values indicate low probability of fish occurrence. (Source: Silga et al., in preparation)

5. SUSFISH Sampling Areas

Komandan Mano and Paul Meulenbroek

Fish and macroinvertebrate data was collected in the two sub-basins of Upper Volta in Burkina Faso: Nakambé and Mouhoun. The Volta basin covers an estimated area of 400,000 km² and is shared throughout six West African countries (Sanwidi, 2007, Béné, 2007). It is represented in Burkina Faso by two sub-basins, the Nakambé (formerly White Volta and Red Volta, now Nazinon) and the Mouhoun (formerly Black Volta), and covers 63.1% (172,968 km²) of the nation's area (GIRE-BF, 2001). The Nakambé (81,932 km^2) is an intermittent river and is highly impounded so as to store water for human and animal use (Cecchi *et al*., 2007). The basin contains 50% of the national population (GIRE-BF, 2001; Cecchi *et al*., 2007). The Mouhoun (92,000 km^2) is a perennial river and the largest in the country. It originates in the south west of the country, flows firstly north through the Bobo Dioulasso region, where precipitation exceeds 1,000 mm/ year, joins the Sourou systems and then turns suddenly and flows south across the country and later forms the Burkina Faso-Ghana border.

The study area extends between the Sourou valley in the northwest, the Boura reservoir in the southwest (border of Ghana) and the Bagré reservoirin the southeast. The sampling took place between 2012 and 2014 and was supplemented with data previously collected between 2008 and 2009. Sampling areas were selected by a consortium consisting of scientists (from BOKU and University of Ouagadougou), local fishermen as well as the Ministry of Environment and Directorate of Fisheries and Aquaculture. Decisive criteria for sampling area selections included: water availability, accessibility, different human stressors, spatial variability, security and travelling costs (SUSFISH, 2014). A total of nine study areas were selected: Boura, Nazinga, Koubri, Koubri_Free, Kougri, Wayen, Bagré, Bobo and Sourou. Each area was further subdivided into different sites. A site is the entity of all nearby and accessible mesohabitats. Map 5 gives an overview of the sampling areas location. Below, each sampling area is described, and detailed maps of the sampling sites are shown. In total, 637 sampling locations (mesohabitats) were investigated in 72 sampling sites.



Map 5: Location of sampling areas

Areas: Koubri and Koubri_Free

The Koubri area is located near to the village of Koubri in the south and 40 km southeast from Ouagadougou. This area consists of the impounded zone on the main course of the Narialé River, a tributary of Nakambé River. Fourteen reservoirs and their connecting sections were targeted. Among targeted reservoirs, the oldest was created in 1960 and the youngest in 1988. Sizes range from 5 to 420 hectares. The sampling area was located between Arzoum-Baongo reservoirs in the east and the downstream of PK25 reservoir in the west. On the northeast bank, Tanvi-, Napagtenga-, Badnogo-, Toyoko-, Mogtedo-, Zeguedse- and Zakin reservoirs were found and in the Southwest side Kogse-, Gonse-, Poedogo-, Kagamzinse- and Wedbila reservoirs were located. Some of these reservoirs frequently dried during the dry season due to their small size combined with high evaporation and water abstraction for irrigation, while Arzoum Baongo, Naba Zana, Poedogo and Napagtenga reservoirs never dry completely.

Koubri_Free sampling areas are part of the Narialé River. It consists of sites located in the free-flowing section between the big reservoir of Arzoum Baongo and the main Nakambé River. Since the disruption of Segda and Peelé reservoirs, this part is free of barriers, and fish can move freely to and from the Nakambé River.

The region around Koubri is characterized by high population density and supports many economical activities such as livestock breeding and rainfed agriculture. In addition, it supported intensive irrigation which continues to increase as a result of growing food demand from the expanding population and economy of Ouagadougou. The northern part of this sampling area is now included in the official periurban perimeter of Ouagadougou.

Sampling Area: Kougri

The Kougri sampling area encompassed the free-flowing sections from the Ziga reservoir downstream to the cross section of Massili/Nakambé and Loumbila downstream of said cross-section. It is mainly characterized by free-flowing river reaches. Between June and August, the upstream reservoirs are filled (Ziga and Loumbila), and this area has a continuous flow. During the dry season it dries up and only rare small pools can be observed in the deeper sections. This area supports rainfed agriculture and livestock breeding, and because it is less populated than the Koubri area, there is less pressure from irrigation.

Sampling Area: Bagré

Bagré is a village located in lower Nakambé River region in southern Burkina Faso in Boulgou province. In 1992, a reservoir was created on the main Nakanbé river in the region around the village of Bagré. The main purpose of the Bagré reservoir creation was hydropower production and irrigation. It is the largest reservoir of Burkina Faso (25,500 hectares) and 23.5 meters deep when full of water. Nine sites, namely Béguédo (2 sites), Béguédo-Niagho, Niagho, Boussouma, Lenga, Foungou, Zangoula, and Bangako were selected in this sampling area. They are all located on the upstream side of the Bagré reservoir with the exception of Bangako. The watercourses feeding the reservoir exhibit continuous flow during the rainy season, and then break into pools during the dry season. The Bagré reservoir supports such activities as rainfed agriculture, rice farming, livestock breeding, fishing, fish farming and irrigation. The human population and human activities are projected to increase due to the development program implementation called “Pôle de Croissance de Bagré” (www.bagrepole.com).

Sampling Area: Nazinga

Nazinga is a protected area located in southern Burkina Faso, at the border of the Republic of Ghana. It is located 60 km from Pô city and covers 91,300 hectares. The Nazinga Game Ranch forest was created in 1979 on a forested area that has been managed since 1953. The main management objectives are to protect and conserve wildlife by controlling human impacts (e.g. agriculture, hunting and fishing). The ranch is crossed by three seasonal brooks: Sissili, Dawevele and Nazinga. Eleven reservoirs were created to provide wildlife with water. The built spillways are lateral types or equipped with fish ladders and might fail to block fish migration (Melcher *et al.*, 2012). This gave fish the possibility to colonize the Ranch. However, they were disregarded as a component in the ranch potentiality and were less investigated as of 2010 (Ouédraogo, 2010).

Nazinga is connected to three other protected areas: National Park Kamboré-Tambi in north, Sissili hunting zone in the southwest and Nazinon classified forest in the east. Human habitations, agricultural activities, cattle breeding and deforestation are forbidden in and near the ranch. Fishing is allowed only from December to April and is strictly controlled. This history of protection and conservation suggested that Nazinga could be assigned as a reference zone for Burkina Faso for comparison with other areas that experience much higher impact levels.

Sampling Area: Boura

Boura is located at the border between Ghana and Burkina Faso. The reservoir of Boura was created in 1983 on a tributary of the lower Mouhoun River (Fowe *et al.,* 2015). It provides water to different irrigated schemes (about 100 ha; >350 farmers) (Poussin *et al*., 2015). The small but significant fishery from this reservoir is immediately absorbed by the local market. During the present study, we sampled in the upstream tributaries and also in the downstream zone of the reservoir. We also sampled in the main Mouhoun after the meeting point with the tributary from Boura.

Sampling sites that are Boromo and Ouessa located on the main Mouhoun are included in this sampling area for analysis.

Sampling Area: Sourou

Sourou is located in northwest Burkina Faso along the border with the Republic of Mali. The Sourou sampling area covers Sourou Valley, which lies partly in Mali and is developed for agriculture. More than 10,000 hectares of water surface are available for fishing and agriculture. Sourou fishery ranks third in terms of national fish production, right after Kompienga and Bagré fisheries. Additionally, Sourou supported economical activities such as livestock breeding, agriculture and irrigation. Sampling sites Lery, Doroula and Badala are included in Sourou area for analysis.

Sampling Area: Wayen

Wayen sampling area encompassed sites belonging to the upper Nakambé. These sites were located upstream of the Ziga reservoir. They supported human activities, such as livestock breeding, rainfed agriculture and fishing. Vegetable farming can be observed in some sites. During the dry season the sites dry up or form isolated small pools in the deeper sections.

Sampling Area: Bobo

The sampling area of Bobo is located in the western part of the country. We sampled in the Kou River and in the Mare Aux Hippopotames. The biosphere reserve of Mare Aux Hippopotames is located between the latitudes 11°30’ and 11°45’ N and the longitudes 04°05’and 04°12’ W. The climate is of the Sudanian type with rainfall averaging around 1,000 mm per year. Climatic constraints have led to more immigration from drier northern areas resulting in significant anthropogenic pressure around the biosphere reserve (extensive agriculture, overgrazing, and fishing) (Dibloni *et al*., 2010).

The Kou River is a perennial river located in the western part of Bobo Dioulasso. It belongs to the upper Mouhoun River. It is connected to the three Nasso-Guinguette springs (Tirogo *et al*., 2016). The Kou River is affected by human activities, amongst others vegetable farming, livestock, agriculture, fishing as well as recreation.

Sampling Area: Banfora

The sampling area of Banfora is located in the border with Cote d'Ivoire and Mali in the southwest of Burkina Faso, about 450 km from Ouagadougou and 85 km from Bobo-Dioulasso. It is characterized by a Sudanian climate with rainfall around 1000 mm. Rainfall occurs in eight months from March to October with three months recording above 150 mm. Banfora is located in the Comoé sub-basin and includes the man-made reservoirs (Moussodougou, Lobi, Banfora, Bounouna etc), one natural lake (Lake Tengrela), multiple rivers and wetlands and the Kafiguéla cascades. A large amount of surface of water is available for fishing and agriculture. Additionally, Banfora is the location of important touristic attractions (Karfeguela Casacade, Hippopotamus in Lake Tingrela). Finally, Banfora area is well known for its sugar cane fields. Fish and macroinvertebrates data were collected in reservoirs (Moussodougou and Bounouma), in natural lake (Tengrela lake) and also in river sections Diarrabakoko and Karfiguela.

6. Macroinvertebrates Sampling

Adama Ouéda, Idrissa Kaboré, Otto Moog, Thomas Koblinger and Daniel Trauner

6.1 Sampling Methodology, Sites and Habitats

Data on invertebrates was compiled from several studies, master and dissertation theses (Guenda, 1996; Ouéda, 2009; Koblinger & Trauner, 2013; Sanogo, 2014; Kaboré, 2016b; Ouédraogo, 2018). Different methods were used to collect quantitative and qualitative invertebrate data. Macroinvertebrates were sampled following a multi-habitats sampling approach, and zooplankton following a transects approach (see Ouéda, 2009). All macroinvertebrates were collected with standard hand and rectangular surber nets, whereas zooplankton was collected with a plankton net, and both were identified using taxonomic manuals, keys (Lévêque & Durand, 1981; Merritt & Cummins, 1984; Tachet *et al*., 2003) and direct taxonomic expert support (Manfred Jäch, Dr. Herbert Zettel, Dr. Albrecht Komarek and Dr. Simon Schneider from the Natural History Museum in Vienna, Dr. Andreas Reischütz, Dr Wolfgang Graf and Thomas Huber from BOKU). This knowledge was summarized in a SUSFISH Handbook for invertebrate identification.

Zooplankton

All the studies that provided data for this study used the same sampling methodology. It consists of the production of vertical, horizontal and oblique lines with a plankton net of mesh size less than or equal to 100 µm. The samples obtained are preserved in formalin (5%) and analyzed under a light microscope equipped with a clear chamber or an inverted microscope.

Annelids

Terrestrial and aquatic annelids were isolated by taking a clump of vegetation and soil that is stirred in the water of a container. The worms are detached from the substrate and, after removal of the plants, the specimens were collected by pipette. Tubificidae and others must be collected with the sediment using a dredge or a skip. The worms are then separated from the substrate by sieving. When possible, worms are examined alive.

Mollusca

The multi-habitat sampling strategy (Barbour *et al*., 1999) was used for the vast majority of study sites. Thus, the molluscs were sampled either with a standard net (frame 25 × 25 cm, meshes 500 µm), with the sediment grab, or by manual collections. Manual collection is carried out for about fifteen minutes on the banks. Samples taken were usually sorted in the field, stored in ethanol (90%) and subsequently measured and identified in the laboratory.

Crustacea

Shrimp and crabs were sampled with a standard hand net (frame 25 × 25 cm, mesh 500 µm). Additionally, shrimp specimen were also collected from commercial fishing with local fishermen in study sites. All samples were stored in ethanol (90%) and identified in the laboratory.

Insects

Different master theses and doctoral dissertations (Guenda, 1996; Koblinger & Trauner, 2013; Sanogo, 2014 and Kaboré, 2016b) shared information on sampling aquatic invertebrates: in particular, insects. Additionally, a publication by Kaboré *et al.* 2016 took a closer look at the families Dytiscidae, Noteridae and Hydrophilidae (Kaboré *et al.,* 2016d). Different gear was used for qualitative and quantitative faunistic data collection. Insects were sampled either with a standard hand net (rectangular opening: 25 cm 9 25 cm, mesh size: 500 µm), surber, or with the sediment grab following the multi-habitat sampling approach (Moog, 2007). Samples were preserved in 90% ethanol and sieved in the laboratory. The animals were sorted under a microscope and identified to the lowest taxonomic level possible based on taxonomic manuals and keys (Lévêque & Durand, 1981; Merritt & Cummins, 1984; Tachet *et al.,* 2003) and with direct taxonomic expert support.

Literature research

The relevant sources of information and data related to invertebrates were collected. This collection includes dissertation theses, articles and books. These sources were accessed through libraries (e.g. all deposits thesis of Université Joseph Ki-Zerbo) and also from web sites.

Sites

The sampling was completed at the sampling sites also used for the fish sampling. These are located in the Koubri, Koubri_Free, Kougri, Bagré, Nazinga, Boura, Sourou, Wayen and Bobo Areas.

Habitats of Benthic Fauna

The benthic fauna sampling was completed in different micro-habitats of rivers, lake and ponds as described in (Kaboré, 2016c). Most of the sampled sites are exhibited a diversity of habitats listed in Table 5.

Table 5: Sampling habitats (choriotopes) of benthic invertebrates

Biotic choriotopes	Rivers	Reservoirs
Algae	Filamentous and Periphyton	Micro-algae and others
Macrophytes	Emerged plants, living part of terrestrial plant.	Submerged plants (Nymphea; Eichhornia; Lactuca) and emergent (Reeds)
Living Wood	Roots, branches, tree trunks	Few
Dead Wood	Branches and trunks	Branches and trunks
COPM	Fallen leaves, others	Residual wastes
FPOM	Detritus	Detritus
Bacteria And Fungi	Yes	Yes
Mineral Choriotopes	**Rivers**	**Reservoirs**
Megalithal	Boulders, Bedrock	Concrete and others
Macrolithal	Cobbles	
Mesolithal	Stones	
Microlithal	Pebbles and coarse gravels	
Alkal	Gravel	Alkal
Psammal	Sand	Sand
Pelal	Mud	Mud

6.2 Biodiversity

In total 219 species of insects and more than forty (40) species of molluscs were collected, counted and identified at genus level. Zooplankton, annelids and crustaceans are also well represented in terms of diversity (Table 6 to Table 10). These results show that the fauna of invertebrates is highly diversified in the water bodies of Burkina Faso. The conservation of biodiversity requires a thorough knowledge of the species richness. These findings (Kaboré *et al.*, 2016a) encourage the use of invertebrates as bioindicators in environmental impact studies, diagnostic studies and ecological monitoring in Burkina Faso. The work of collecting information and data should continue to help establish an exhaustive taxonomic list of invertebrates in Burkina Faso.

Zooplankton

Table 6: List of found Zooplankton genus

PHYLUM	CLASS	ORDER	FAMILY	GENUS
ARTHROPODA	Branchiopoda	Diplostraca	Bosminidae	Bosmina
			Chydoridae	Alona
				Chyrodus
				Leydigia
			Daphnidae	Ceriodaphnia
				Daphnia
			Macrothricidae	Guernela
				Macrothrix
			Moinidae	Moina
				Moinodaphnia
			Sididae	Diaphanosoma
	Insecta	Diptera	Chaoboridae	Chaoborus
	Maxillopoda	Calanoïda	Diaptomidae	Tropodiaptomus
		Cyclopoida	Cyclopidae	Macrocyclpos
				Mesocyclops
				Neocyclops
				Tropocyclpos
CNIDARIA	Hydrozoa	Limnomedusae	Olindiidae	Limnocnida
ROTIFERA	Eurotatoria	Collothecacea	Collothecidae	Collotheca
		Flosculariaceae	Hexarthridae	Hexarthra
			Testudinellidae	Pompholyx
				Testidunella
			Trochosphaeridae	Filinia
		Ploima	Asplanchnidae	Asplanchna
				Asplanchnopus
			Brachionidae	Anuraeopsis
				Brachionus
				Keratella
				Platyas
			Epiphanidae	Epiphane
			Gastropodidae	Ascomorpha
				Grastropus
			Lecanidae	Lecane
			Synchaetidae	Ploesoma
				Polyharthra
			Trichocercidae	Trichocerca
			Trichotriidae	Trichotria
				Plygura

Annelids

Table 7: List of found Annelid genus

CLASS	ORDER	FAMILY	GENUS
CLITELLATA	Haplotaxida	Acanthodrilidae	Millsonia
		Acanthodrilidae	Dichogaster
		Eudrilidae	Legonea
	Hirudinea	Hirudinea	Hirudinea

Mollusca

Table 8: List of found Mollusc genus

CLASS	ORDER	FAMILY	GENUS
BIVALVIA	Unionoida	Etheridae	Etheria
		Iridinidae	Aspatharia
			Chambardia
			Mutela
		Unionidae	Coelatura
	Veneroida	Sphaeridae	Sphaerium
			Eupera
	Venerida	Cyrenidae	Corbicuta
GASTROPODA	Architaenioglossa	Ampullaridae	Lanistes
			Pila
		Viviparidae	Bellamya
	Hygrophila	Lymnaeidae	Lymnaea
		Planorbidae	Biomphalaria
			Bulinus
	Sorbeoconcha	Paludomidae	Cleopatra
			Potamoda
		Thiaridae	Melania

Crustacea

Table 9: List of found Crustacean genus

CLASS	ORDER	FAMILY	GENUS
MALACOSTRACA	Decapoda	Atyidae	Caridina
		Palaemonidae	Macrobrachium
		Gecarcinucidae*	-
		Potamonautidae	Potamonautes
OSTRACODA*	Ostracoda	-	-

*Further identification was not possible

Insects

Table 10: List of found Insect families

ORDER	FAMILY
EPHEMEROPTERA	Baetidae
	Ephemeridae
	Caenidae
	Heptageniidae
	Leptophlebiidae
	Oligoneuridae
	Potamantidae
	Tricorythidae
	Polymitarcidae
	Taeniopterygidae
PLECOPTERA	Perlildae
LEPIDOPTERA	Pyralidae
ORTHROPTERA	Gryllotalpidae
	Tridactylidae
ODONATES	Chlorocyphidae
	Aeshnidae
	Chlorolestidae
	Coenagriidae
	Corduliidae
	Gomphidae
	Libellulidae
HEMIPTERA	Belostomidae
	Hydrometridae
	Nepidae
	Corixidae
	Gerridae
	Naucoridae
	Notonectidae
	Pleidae
	Saldidae
	Veliidae
COLEOPTERA	Dysticidae
	Staphilinidae
	Psephenidae
	Chrysomelidae
	Noteridae
	Elmidae
	Hydrophilidae
	Gyrinidae
	Curculionidae
	Dryopidae
	Haliplidae
	Helodidae
	Scirticidae
	Spercheidae
ORDER cont.	**FAMILY cont.**
TRICHOPTERA	Glossosomatidae
	Limnephilidae
	Hydropsychidae
	Ecnomidae
	Polycentropodidae
	Philopotamidae
	Leptocderidae
DIPTERA	Hydroptilidae
	Simuliidae
	Ceratopogonidae
	Chaoboridae
	Culicidae
	Ephydridae
	Anthomyidae
	Syrphidae
	Muscidae
	Stratiomyidae
	Rhagionidae
	Tabanidae
	Limoniidae
	Psychodidae
	Chironomidae

Dytiscidae, Noteridae* and *Hydrophilidae

A study conducted in 2016 by Kaboré *et al.* took a closer look at the diversity and environmental pressure responses of the aquatic beetle families *Dytiscidae, Noteridae* and *Hydrophilidae*. Coleoptera (Beetles) are often found in in habitats which are sensitive to human alterations and can thus be used as biondicators for water quality (Sánchez *et al.,* 2006; Guareschi *et al.*, 2012). In this study a total of 60 species of water beetles was found in a variety of habitats, most belonging to the families *Ditiscidae* (27), *Hydrophilidae* (22) and *Noteridae* (11). It was found that the water body typology and aquatic plant habitats are the key determinants of aquatic beetle species distribution. The highest species richness was found in reservoirs covered by reed vegetation while the lowest level was found in rivers with a high sediment load. Physio-chemical parameters such as temperature, conductivity, pH and dissolved oxygen on the other hand had less influence on the species distribution (Kaboré *et al*., 2016d).

6.3. Results for Applied Limnology and Water Management

The studies on benthic macroinvertebrates were undertaken under the auspices that efficient monitoring tools to assess the ecological status of aquatic ecosystems are urgently needed in West Africa, especially in Burkina Faso. The diploma thesis by Ouédraogo, I. (2013) gives first insights into the influence of chemical factors on the spatial distribution of zooplankton in two big urban reservoirs in Ouagadougou. The master thesis by Koblinger & Trauner (2013) on the topic "Benthic invertebrate assemblages in water bodies of Burkina Faso" provides a first informative basis for the SUSFISH project. In his doctoral thesis, Sanogo, S. (2014) describes the macroinvertebrate inventory of different water bodies in the Volta basin in view of the identification of bioindicator taxa in an effluent-hydroagricultural dam continuum river in Burkina Faso. The scientific publication of Kaboré et al (2016c) on the topic "macrozoobenthos” in Burkina Faso describes the diversity, composition and structure of benthic macroinvertebrate communities in semi-arid rivers of Burkina Faso. The authors recorded a high diversity of benthic macroinvertebrates with a total of 132 taxa belonging to 57 families from 8 orders of insects. The results revealed a strong relationship between midges (Chironomidae, hoverflies (Syrphidae), and mosquitoes (Culicidae), drain flies (Psychodidae), as well as pulmonate snails (Pulmonata) and organic nutriments. Kaboré et al (2016d) expanded knowledge of the invertebrates with the study on the diversity and ecology of diving beetles (Dytiscidae, Noteridae) and water beetles (Hydrophilidae)in the rivers and reservoirs in Burkina Faso. The study demonstrated the importance of aquatic vegetation for this group of animals, which had so far been neglected. Within the high number of 60 water beetle species, 24 species were newly proven for Burkina Faso. Ouédraogo, I. (2018) provides valuable information on the biodiversity and distribution of the taxonomic group of mollusks. Kaboré *et al.* (2016a) explore the potential use of macroinvertebrate communities for aquatic bio-assessment in semi-arid areas of West Africa. In 29 investigated sampling sites of running waters, 100 taxa from 58 families were recorded. The results showed that different metrics of diversity, composition and tolerance of macroinvertebrate communities, as well as indicator taxa, showed differential sensitivity to different levels of environmental degradation and a clear trend across the gradient of human impact intensity in terms of land use. Another important basis for the development of water monitoring is the work of Kaboré *et al*. (2018). This study examines the environmental variables (physicochemical, hydro-morphological, and land use) from 44 investigation sites and identified 'a priori criteria' in Burkina Faso to describe reference conditions, which serves as an inevitable foundation for a future reference condition based bio-assessment methodology.

7. Fish Sampling

Komandan Mano and Paul Meulenbroek

7.1. Sampling Methodology

Fish sampling was conducted in the reservoirs and river sections in the Upper Volta catchment. Fish were collected during both high and low water levels. Water bodies were sampled with three traditional fishing methods (gill net, cast net and long line) and with electric fishing. The small bodies of water were completely fished, while the larger ones were sampled at different points. The aim was to cover all typical habitats and to collect a large variety of species. Cast net and electric fishing were widely used during this study.

Electric fishing was conducted with backpack-generator ELT60-IIH following the methods of Hans Grassl (Grassl, 2012). The generator has 1.3 kW and can be switched between 300 V and 500 V. Due to low water conductivity in Burkina Faso, electric fishing was performed with 500 V. The anode ring has a 30 cm diameter with 5 mm mesh size in the centre. Each operation was performed by at least three people per trial: one to carry and operate the generator, one to land the fish and the third participant serves as security and to empty the net. Elapsed time was recorded, and the area of fishing was estimated to make fishing results comparable. Electric fishing was always performed by wading (Brousseau *et al*., 2005).

Two professional fishermen were recruited to perform traditional cast-net fishing. Two kinds of net were used, one with 10 mm mesh size and 4.3m diameter, the other one with 25mm mesh size and 4.5m diameter. The number of throws was noted for comparison. Most of the time the fishermen were wading, and for some deeper areas they used a canoe (Hayes *et al*., 1996). There is a video available in which Noufou Bonkoungou (fisherman with 40 years of experience) is explaining how to operate with a cast net (http://susfish.boku.ac.at/movies.htm). Gill net and long line were set in the afternoon at 5 pm and lifted the following day at 7 am by the fishermen. While in Nazinga, the gill net was placed only for 1 to 2 hours. The used gill net had three mesh sizes, each of 30, 40 and 50 mm. When possible, electric- and cast net fishing was applied in the same site. Electric fishing was allowed only for scientific purpose.

Figure 26: Electric fishing with generator in streams (Source: A. Melcher)

Figure 27: Fish (Malapterurus electricus) being measured for length in the field (Source: S. Stranzl)

Figure 28: Capture and identification of fish in the field (Source: A. Melcher)

Figure 29: Cast net fishing (Source: Meulenbroek et al. 2019)

Identification and Training of Experts/Sampling Team

A team of 8 national experts, overseen by an expert from IUCN's Species Survival Commission, contributed to this assessment. They are researchers, senior researchers and practitioners of the Laboratory of Biology and Animal Ecology (LBEA) of the University Ouagadougou Pr Joseph Ki-Zerbo, Institute of Rural Development of the Polytechnic University Nazi Boni of Bobo Dioulasso, Directorate General of Fisheries Resources of the Ministry of Animal and Fisheries Resources, Institute of Environment and Agricultural Research (INERA) of the National Center for Scientific and Technological Research (CNRST) and the University of Abomey Calavi from Benin These experts received scientific support from colleagues at the University of Natural Sciences (BOKU) in Vienna, the Natural History Museum in Vienna, the Royal Museum of Central Africa in Belgium and the Institute de Recherche pour le Développement (IRD).

The team received targeted training on the IUCN species conservation status assessment process and tools from 20 to 24 May 2013. It was provided by Philippe Laleye, a member of the IUCN Fish Group. In addition to the recalls on the anatomy and systematics of fish and invertebrates, the training helped to identify the types of data to be collected for the assessment, to become familiar with the assessment categories and criteria and the module for Input of the IUCN Species Information Service (SISDEM).

Fish Identification

A hotkey for fish species determination in the field was developed for the project. It was compiled based on Burkina Faso's fish species list, following literature research in cooperation with IUCN (Central and West Africa). The main reference documents were determination keys established for West Africa (Paugy *et al*., 2003a; b; Lévêque et al., 1990; 1992). After sampling, fish were sorted, identified to species level and measured for total length. Fish that could not be identified to species level were then measured, sacrificed and fixed in 70% alcohol and were brought as voucher fish specimens to the laboratory at University of Ouagadougou Joseph Ki-Zerbo for species collection.

In the laboratory, more detailed morphological characteristics, namely teeth, gills, eyes, scales, fins were subjected to closer investigation for a correct species identification. Additionally, this further identification received the support of fish experts from the Royal Museum for Central Africa, Tervuren/Belgium.

7.2. SUSFISH Species List

The first phase of SUSFISH lasted from November 2011 to November 2014 during which period fish data collection was started and many areas were visited, including: the highly impounded zone Koubri, the big dam of Bagré and its upstream tributaries, the agricultural zones Sourou and Boura, the upper part of Nakambé (Wayen), the upper of Mouhoun: the area of Bobo, and the protected area Nazinga. Altogether, fish data was collected in more than 50 sites.
In this first phase of the project 44,788 individuals were caught belonging to over 79 fish species in 19 fish families were identified. The most individuals found belonged to the families Cyprinidae and Cichlidae. Figure 30 shows a summary of all species found. The corresponding sampling sites where species were found are listed in Table 11 & Table 12.

After three years of fruitful collaboration, a second phase (SUSFISH+) was funded as a follow-up project to capitalize on the initial achievements. During this period, the area of Bobo Dioulasso, Banfora and Bourra were visited for sampling. Some fish species, e.g. *Chromidotilapia guntheri, Petrocephalus soudanensis and Campylomormyrus tamandua* could be added to the existing list. Beyond the diversity, important information on fish ecology was generated during these two phases. Further work on the use of genetic markers for identification is ongoing. The data gathered represents useful information for sustainable fisheries in the areas of aquatic ecology.

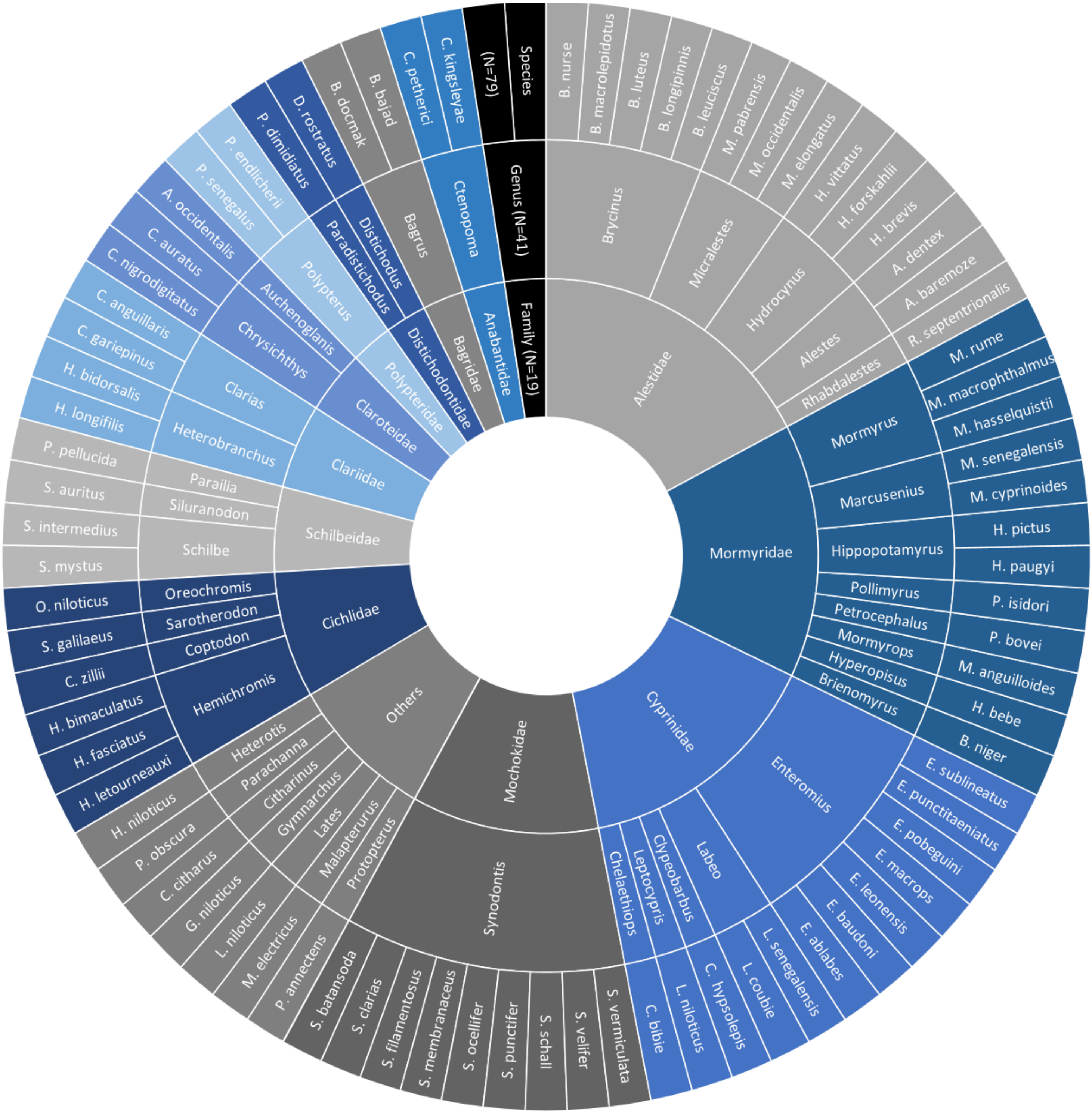


Figure 30: Sunburst graph illustrating all species (79), genera (41) and families (19); Family of Channidae, Citharinidae, Gymnarchidae, Latidae, Malapteruridae, Protopteridae and Arapaimidae are shown as 'others'.

Table 11: Summary of caught species assigned to sampling areas n= 44,788 Individuals (X – indicates presence of species in sampling area) (Mano, 2016)

Family (N=19)	Genus (N=41)	Species (N=79)	Sampling Area (N=9)									N of occurred habitat
			Bagré	Bobo	Boura	Koubri	KoubriF	Kougri	Nazinga	Sourou	Wayen	
Alestidae	Alestes	*A. baremoze*	X		X	X	X	X	X	X		50
		A. dentex	X		X	X	X	X	X	X		32
	Brycinus	*B. leuciscus*				X	X	X				3
		B. longipinnis	X		X		X	X	X	X		10
		B. luteus	X				X	X	X	X		27
		B. macrolepidotus							X	X		13
		B. nurse	X	X	X	X	X	X	X	X	X	225
	Hydrocynus	*H. brevis*							X	X		2
		H. forskahlii			X		X		X	X		26
		H. vittatus							X			1
	Micralestes	*M. elongatus*							X			1
		M. occidentalis	X			X	X	X		X		15
		M. pabrensis						X				1
	Rhabdalestes	*R. septentrionalis*	X		X	X	X	X	X	X	X	81
Cyprinidae	Enteromius	*E. ablabes*				X	X	X	X		X	117
		E. baudoni	X			X	X	X	X	X		17
		E. leonensis	X		X	X		X				23
		E. macrops	X	X	X	X	X	X	X	X	X	323
		E. pobeguini	X			X		X				4
		E. punctitaeniatus						X				1
		E. sublineatus		X								9
	Chelaethiops	*C. bibie*	X			X	X	X	X	X	X	85
	Labeo	*L. coubie*	X		X		X	X	X	X		47
		L. senegalensis	X		X			X	X			57
	Leptocypris	*L. niloticus*	X		X	X	X	X	X	X	X	52
	Clypeobarbus	*C. hypsolepis*	X		X	X			X			8
Mormyridae	Brienomyrus	*B. niger*			X	X	X	X	X			12
	Hippopotamyrus	*H. paugyi*							X			3
		H. pictus	X		X	X	X		X			25
	Hyperopisus	*H. bebe*	X			X	X	X	X	X	X	41
	Marcusenius	*M. cyprinoides*								X		3
		M. senegalensis	X	X	X	X	X	X	X	X	X	92
	Mormyrops	*M. anguilloides*	X				X		X			3
	Mormyrus	*M. hasselquistii*							X			5
		M. macrophthalmus			X				X	X		5
		M. rume	X		X	X	X	X	X	X	X	43
	Petrocephalus	*P. bovei*	X	X	X	X	X	X	X	X		54
	Pollimyrus	*P. isidori*	X	X	X	X	X	X	X	X	X	43

Table 12: continuation of species summary assigned to sampling areas n= 44,788 Individuals (X – indicates presence of species in sampling area) (Mano, 2016)

Family (N=19)	Genus (N=41)	Species (N=79)	Sampling Area (N=9)									N of occurred habitat
			Bagré	Bobo	Boura	Koubri	KoubriF	Kougri	Nazinga	Sourou	Wayen	
Mochokidae	Synodontis	*S. batansoda*								X		1
		S. clarias			X				X	X		14
		S. filamentosus							X			1
		S. membranaceus	X				X	X		X		22
		S. ocellifer					X	X				2
		S. punctifer				X						16
		S. schall		X	X	X	X	X	X	X	X	135
		S. velifer	X						X			2
		S. vermiculata							X			1
Cichlidae	Hemichromis	*H. bimaculatus*	X	X	X	X	X	X	X	X		108
		H. fasciatus	X	X	X	X	X	X	X	X	X	66
		H. letourneauxi				X	X		X			19
	Oreochromis	*O. niloticus*	X	X	X	X	X	X	X	X	X	300
	Sarotherodo	*S. galilaeus*	X	X	X	X	X	X	X	X	X	305
	Coptodon	*C. zillii*	X	X	X	X	X	X	X	X	X	269
Clariidae	Clarias	*C. anguillaris*	X	X	X	X	X	X	X	X	X	134
		C. gariepinus				X	X		X			95
	Heterobranchus	*H. bidorsalis*						X	X			15
		H. longifilis							X			2
Schilbeidae	Parailia	*P. pellucida*	X	X			X	X				17
	Schilbe	*S. intermedius*	X	X	X	X	X	X	X	X	X	112
		S. mystus	X		X	X	X	X	X	X		32
	Siluranodon	*S. auritus*			X	X	X			X		11
Claroteidae	Auchenoglani	*A. occidentalis*	X			X	X	X	X	X		43
	Chrysichthys	*C. auratus*	X		X	X	X	X		X		20
		C. nigrodigitatus	X			X	X	X				22
Anabantidae	Ctenopoma	*C. kingsleyae*		X	X	X	X	X	X			34
		C. pethericii					X					4
Bagridae	Bagrus	*B. bajad*	X		X		X	X	X	X	X	49
		B. docmak	X				X	X	X			18
Distichodontidae	Distichodus	*D. rostratus*	X		X			X	X	X		22
	Paradistichod	*P. dimidiatus*		X	X					X		10
Polypteridae	Polypterus	*P. endlicherii*							X			4
		P. senegalus	X	X	X	X	X	X	X	X	X	27
Arapaimidae	Heterotis	*H. niloticus*		X						X		7
Channidae	Parachanna	*P. obscura*		X	X							7
Citharinidae	Citharinus	*C. citharus*							X			2
Gymnarchidae	Gymnarchus	*G. niloticus*		X						X		3
Latidae	Lates	*L. niloticus*	X		X	X	X	X	X	X		79
Malapteruridae	Malapterurus	*M. electricus*		X		X	X	X	X	X		7
Protopteridae	Protopterus	*P. annectens*		X	X	X						16
Total N species			42	23	39	42	49	49	58	45	19	
Total N Genus			29	21	30	29	33	31	33	32	18	
Total N Families			12	15	15	13	13	14	15	15	9	

Furthermore, within this project Meulenbroek *et al*. (2019) described that these fish communities cluster into four distinct types, each dominated by one famly, either *Cichlidae*, *Clariidae*, *Cyprinidae,* or *Alestidae* and accompanied by specific other families and genera of fish. Additionally, habitat preferences and sensitivity to human pressures are described in this study.

7.3. Studying the Molecular Biodiversity with DNA Barcoding

Nikolaus Schobesberger and Harald Meimberg

Following the multifaceted approach of the SUSFISH projects, another tool is being developed in an ongoing master thesis in order to equip decision makers with the competence to drive socioeconomic processes forward. Molecular determination can serve as a complementary tool to successfully operate a standardized monitoring and assessment of fish stocks (Hebert *et al*., 2003). DNA barcoding has proven to be an efficient tool for showing divergence among species that may look morphologically indistinguishable (Knebelsberger *et al*., 2014). It can be used to detect cryptic diversity in species or reveal taxonomic inconsistencies, which are prevalent in Burkina Faso's freshwater fish (Meulenbroek, 2013). In the course of creating a DNA barcode reference library for the freshwater fish of Burkina Faso, this question may be addressed to get an overview of selected genera, both morphologically and genetically. In addition, the genetic makeup of fish species can be compared between the two river catchments Mouhoun and Comoé by determining differences in the Haplotypes.

Methods of DNA Barcoding

Field work was done in the frame of a master thesis for three weeks in January 2019, the middle of the dry season. Various sites in two different catchments were fished; in Black Volta or Mouhoun (around the city of Bobo-Dioulasso and in the area of Boura) and the Comoé catchment (around the small town of Banfora). The catchments and subsequent sites were selected based on accessibility and previous studies that were done in the country to create comprehensive data.

For determination of haplotypes within the two catchments, collected fish were identified on species level by Dr. Mano Komandan and stored in 70% undenatured alcohol (Stein *et al*., 2013). DNA samples were taken by fin clips from the pectoral fins of big fish and muscle tissue for small fish, from the dorso-lateral muscles (Knebelsberger *et al*., 2014) for a minimum 10 specimens prer species per site. In the Lab, Primers (VF2_t1 [CAACCAACCACAAAGACATTGGCAC], VR1_t1 [TAGACTTCTGGGTGGCCAAAGAATCA], Ward *et al*., 2005) for the Polymerase Chain Reaction amplification (PCR) (Meimberg *et al*., 2016) were determined using the Basic Local Alignment Search Tool (BLAST) (Altschul *et al*., 1997). A DNA Library of the mitochondrial genome was created by Illumina Sequencing using the ThruPLEX® DNA-Seq Kit (Meimberg *et al*., 2016) and analyzed with python scripts provided by Dr. Manuel Curto (University of Life Sciences Vienna, Institute for Integrative Nature Conservation Research). Reliability and performance of the used primers for determination of various fish genera was crosschecked by comparing sequencing data to the BLAST library in BOLD (Barcode Of Life Data System) and NCBI (National Centre for Biotechnology Information). Sequences required were concatenated and aligned haplotypes were created and processed in Geneious 9.2.3 (https://www.geneious.com/) and PopART (http://popart.otago.ac.nz/index.shtml, Bandelt *et al*., 1999) to check for gaps and missing data. A maximum-likelihood phylogeny was calculated (PhyML 3.0) and minimum spanning networks were selected to visualize the relationship within species. For species identification the COI (Cytochrome Oxidase Subunit 1) region was selected and compared to the Chordata BINs database (http://www.boldsystems.org/) using Geneious 9.2.3 (https://www.geneious.com/).

Species List Based on Morphological Identification

A total of 411 fish were caught during these three weeks (112 in the Comoé catchment and 299 in the Mouhoun). 14 families containing 27 genera were caught, of which 33 species could be determined morphologically. The most diverse family was the Alestidae with 8 different species, second most diverse was the Cichlidae with 6 different species. In the Comoé catchment, 12 different species were caught, while in the Mouhoun the number of species was 29, based on morphological determination.

The family that is represented in the highest abundance are the Cichlidae with 177 individuals, second most abundant the Alestidae with 116 individuals.

Rare species like *Petrocephalus soudanensis, Synodontis membranaceus, Auchenoglanis occidentalis, Ctenopoma kingsleyae, Bagrus bajad and Heterotis niloticus* were only caught once. For both catchments, the ratio of species to caught fish was around 1:10. This indicates the greater number of species in Mouhoun catchment stems from a greater number of samples (Table 13).

Mitochondrial Markers for Haplotype Identification

To verify fish identification and to determine potential differences in the two river catchments difference in the mitochondrial haplotypes of fish species had been investigated. This is traditionally performed using the mitochondrial COI region as DNA barcode, which was also applied in the study (Hebert et al., 2004, Knebelsberger *et al*., 2014). in addition, a wider range of markers was included to develop a more comprehensive dataset on haplotypes, especially to compare the two rivers (Amin *et al*., 2015). 33 markers were constructed covering the whole mitochondrial genome in comparison to *Oreochromis niloticus.* Sequencing of all loci and samples has been done using the Illumina approach and are currently under analysis. So far COI sequences for 194 individuals are available and have been analyzed (Figure 31). A phylogeny tree from COI barcoding region sequences was constructed and haplotype identities are inferred from there.

Table 13: Summary of caught species in two catchments in three sampling areas (Source: Schobesberger, 2020)

Family (N=14)	Genus (N=27)	Species (N=33)	Sampling Catchment (N=2) Sampling Area (N=3)			N of fish per sp.
			Comoé	Mouhoun		
			Banfora	Bobo	Boura	
Alestidae	Brycinus	*B.*		1	2	3
		B. nurse		17	7	24
	Micralestes	*M. occidentalis*		7		7
		M. sp.			2	2
	Rhabdalestes	*R.*		12	1	13
	Enteromius	*E. macrops*	14	17	10	41
		E. sublineatus		14		14
	Labeo	*L. senegalensis*	1		5	6
		L. sp.		1		1
	Raiamas	*R. senegalensis*		3		3
Alestiadae sp.				2		2
Mormyridae	Hippopotamyr	*H. pictus*			2	2
	Marcusenius	*M. senegalensis*	3			3
	Petrocephalus	*P. soudanensis*			1	1
Mochokidae	Synodontis	*S.*			1	1
		S. nigrita		12	18	30
		S. punctifer		2		2
		S. schall			12	12
Cichlidae	Chromidotilapi	*C. guntheri*	6			6
	Coptodon	*C. zillii*	18	13	9	40
	Hemichromis	*H. bimaculatus*	7	9	11	27
		H. Fasciatus	17	7	10	34
	Oreochromis	*O. niloticus*	16	5	14	35
	Sarotherodon	*S. galilaeus*	11	11	13	35
Claroteidae	Auchenoglanis	*A. occidentalis*			1	1
	Chrysichthys	*C. auratus*	10	1	2	13
		C. sp	1			1
Distichodontidae	Distichodus	*D. rostratus*			1	1
	Paradistichodu	*P. dimidiatus*		4	9	13
Clariidae	Clarias	*C. anguillaris*		8	3	11
		C. sp.	1	1		2
Schilbidae	Schilbe	*S. intermedius*		12		12
Anabantidae	Ctenopoma	*C. kingsleyae*		1		1
Bagridae	Bagrus	*B. bajad*			1	1
Polypteridae	Polypterus	*P. endlicherii*			2	2
Arapaimidae	Heterotis	*H. niloticus*	1			1
Channidae	Parachanna	*P. obscura*		2		2
Latidae	Lates	*L. niloticus*	6			6
		Total N	33		**Total**	411
		Total N Genus	27			
		Total N	14			

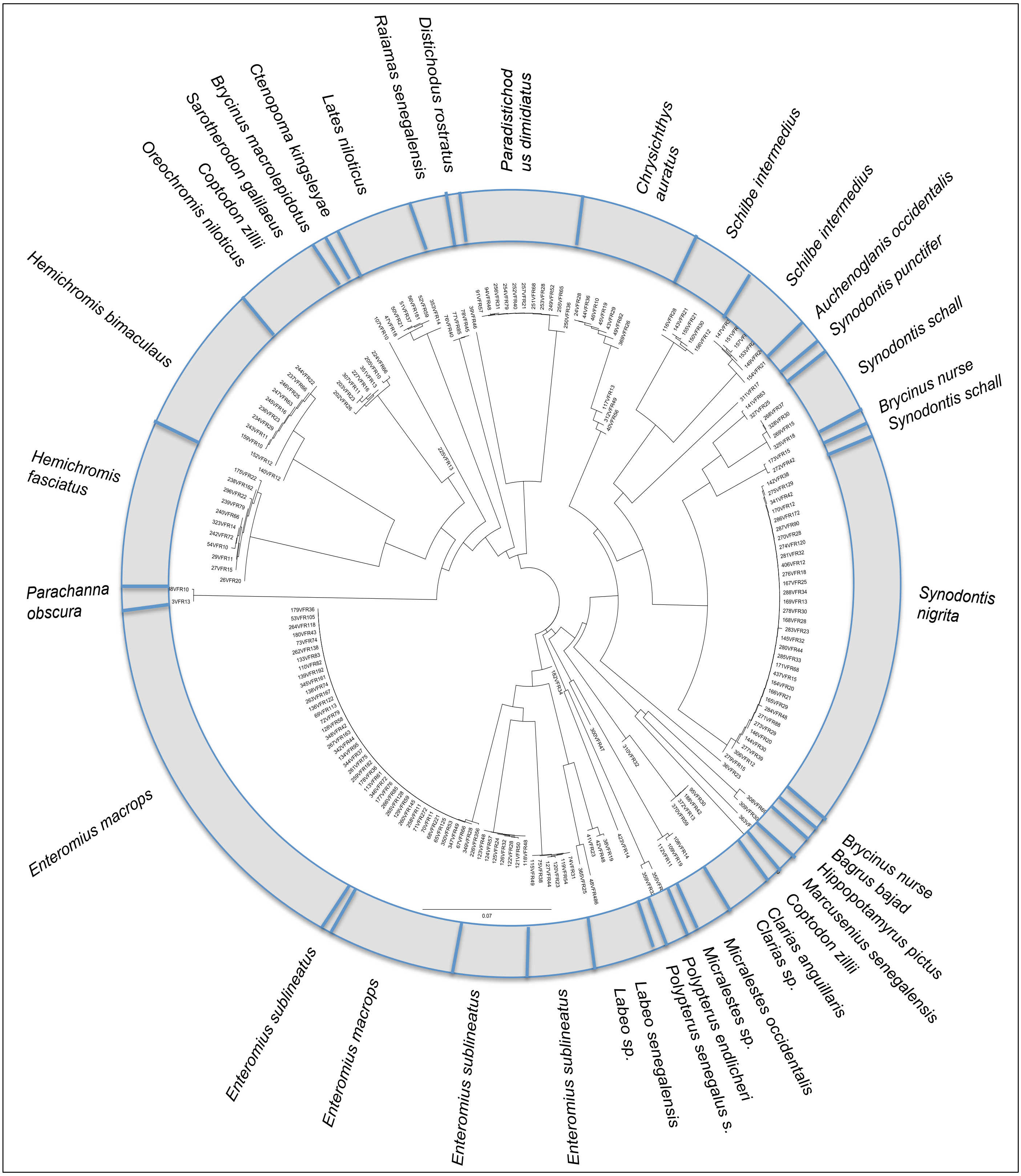


Figure 31: Neighbor joining tree from COI senquences of 194 samples collected in the Mouhoun and Comoé catchments. Not yet included are the species: Rhabdalestes septentrionalis, Chromidotilapia guntheri, Petrocephalus soudanensis, Alestidae sp., Heterotis niloticus.

The Haplotype for most species forms one terminal branch indicating clear species assignment. That different species comprise very similar haplotypes was observed in the Cichlids. The Cichlid family appears to be presented by three distinct clades, two include the *Hemichromis* genus with the two species *H. fasciatus* and H. *bimaculatus* each on one clade but comprising several close related haplotypes. The third branch includes three species: *Oreochromis niloticus, Coptodon zillii, and Sarotherodon galilaeus,* (subfamily Pseudocrenilabrinae) which share one clade of haplotypes, indicating low genetic structure between the species concerning mitochondrial DNA. This indicates the possibility of occasional hybridization between the three species that were formerly treated as congeneric (Tilapia; e.g. Tibihika *et al*., 2019) *Ctenopoma kingsleyae* and *Parachanna obscura* of the order Anabantiformes are present in distinct branches neighboring the Cichlids. One *C. zillii* individual is positioned deviating from these clades. Because it has an own haplotype differentiated by high distance from the next neighbor the individual was probably misidentified. Shared haplotypes between close related species were identified also for the species *E. macrops* and *E. sublineatus* with one individual. This can be due to misidentification or occasional genetic exchange. Four species showing a clear differentiation in haplotypes exceeding the distance normally associated with species differences. *E. sublineatus* samples form a group with two clearly differentiated haplotypes of about 12% sequence divergence. The same is the case with *Schilbe intermedius*, in both cases the two groups occur within one catchment indicating the existence of additional sympatric species that have not been recognized morphologically. *Chrysichthys auratus* forms two groups of haplotypes. Here the groups are correlated to the two catchments and could indicate differentiation between them. *Synodontis schall* is divided into two groups. The Synodontidae appear therefore as four groups while only three are morphologically identified. Hereby, *Synodontis punctifer* and *Synodontis nigrita* present one group respectively. The positions of *Brycinus nurse* individuals in these groups are probably erroneous.

The haplotype differentiation between catchments within a species group has to be analyzed further. So far, we can support the abundance and occurrence for 33 morphologically determined species in addition to 4 species not yet recognized. In continuation of the project sequences for all samples will be generated.

8. Socio-Economic Aspects

8.1. Governance and Management Strategies

Vincent-Paul Sanon, Pousga Alphonse Kiendrebeogo and Patrice Toé

The management of the environment requires sufficient and adequate authority (Perrot, 1989), and institutions are the means by which society establishes, shapes and implements that authority. Institutions are of high importance in natural resources management since they determine whether, how, how much, when and for how long people can access which resources. They also influence whose voice is important in decision-making and the kind of practices that are allowed (Nunan *et al.*, 2015). Therefore, this chapter will give some insight into fisheries management in Burkina Faso based on studies in the western part of Burkina Faso.

Different Type of Fishing and Management in Burkina Faso Fisheries

Fishing is exclusively artisanal (Zerbo *et al.*, 2013). However, the Forest Code in force nationally since 1997 recognizes four types of fishing that are distinguished by their purpose: (i) commercial fishing for profit, giving rise to the sale of all or part of the catch, (ii) subsistence or customary fishing that is intended for consumption by the fisherman and his family and does not give rise to the sale of the catch, (iii) sport fishing that is practised for non-profit purposes such as recreation; (iv) scientific or pedagogical fishing as practised for study and scientific knowledge of the halieutic resources.

Additionally, the Forest Code provides four management systems:

- The fishing concession is applied to small and medium water bodies. It is the contract for payment by which the State entrusts to a natural or legal person under private law, the exclusive exploitation of the fishery resources of all or part of a water body (Assemblée des Députés du Peuple, 1997a; Assemblée Nationale, 2011). Such concessions have been implemented for the reservoirs of Bapla, Léra, Moussodougou, and Tandjari. The exploitation right is acquired at the price of 3000 FCFA/ha/year (around 4,50 Euros).

- Périmètre Halieutique d'Intérêt Economique (PHIE) (Fishery Perimeters of Economic Interest) are key perimeters with a focus on of economic development. They consist of water bodies greater than 5,000 hectares during low-water periods which have significant economic importance and whose fisheries resources are threatened by overexploitation (Assemblée des Députés du Peuple, 1997a, 1997b). Ten fisheries including the Bagré, Kompienga, Sourou, Ziga, Bam, Yakouta, Sirba, Toessé, Douna and Samandeni Lakes have been classified as PHIE. They are subject to co-management arrangements, where stakeholders including fishing communities, decentralised technical services, local authorities, traditional authorities, NGOs, and microfinance institutions, are involved in the decision-making process within a committee chaired by the governor of the region. Fishing requires a fishing permit specific to each PHIE.
- Management in Protected Areas is a specific type of management for fisheries exploitation in wildlife protection areas and classified forests. The fisheries in this category include Arly, Pendjari, and Nazinga and are managed by a fishing guide.
- Open access includes all other fisheries excluding the concessions, the protected areas, and the PHIE. The only requirement in these areas is the fishing permit.

In Burkina Faso, about 11,778 households have at least one fishing related activity (Zerbo *et al.*, 2013). Stakeholders directly involved in fishing are estimated to be 41,366 (except traders of inputs and fishing equipment as well as fish farmers). According to the General Census of Agriculture (RGA) in 2007, these direct actors are made up of:

- fishermen (32,699), 14% of whom are women;
- processors (2,983), 82% of whom are women;
- fishmongers (3,375), 54% of whom are women;
- smoked fish traders (2,309), 66% of whom are women (Zerbo *et al*. 2013).

Foreign fishers are allowed in any fishery, yet 90% of the fishers' households are Burkinabe while the rest are from Benin, Niger and Mali (Zerbo *et al.*, 2013). The price of fishing permits varies depending on age, nationality and type of fishing. A commercial fishing permit for young Burkinabe fishers is the least expensive (8,000 F

CFA) and a sport fishing permit for foreign fishers without residency is the most expensive (30,000 F CFA) (MEE and MEF, 2003).

Implementation and Constraints of Fisheries Governance

The overall implementation of fishery management systems as described above is allocated to the ministry in charge of animal and fishery resources. This ministry is also represented in regional and local administration that sets management plans, controls the means for regulatory compliance and empowers the actors through organization and training. Additionally, it provides fishing permits and licenses for fish trade. However, a series of institutional changes assigning fisheries management to different ministries (Table 1 on page 12) (Bouda, 2002; Toé and Sanon, 2015; Kiendrebéogo, 2018; MRAH and MIR, 2018) weakened the implementation of regulation (Toé and Sanon, 2015; Kiendrebéogo, 2018). The irregularity of policing controls on the water results in the use of fishing gears that do not comply with the regulations (Fofana, 2018).

Fishing regulation is not implemented solely by the national government, and the implementation of national fisheries regulations has disrupted traditional fisheries management structures (Bouda, 2002; Toé and Sanon, 2015; Kiendrebéogo, 2018). However, traditional law still governs access to natural resources, e.g. water and land in the village and undeveloped land in urban areas (Bouda, 2002). If the fishermen can take advantage of a fishing license granted by the national legislation, they must deal with other users who rely on rules rooted in traditions that give water ownership to the riparian populations. Hence, traditional authorities and customary law still have legitimacy in rural communities where people rely on it to solve their problems, particularly to guarantee their access to the resources. Thus, alongside modern institutions, traditional chiefs play a role in the present management of fisheries (Table 1 on page 12). For example, they are asked to perform their traditional customs on the water such as those shown in Table 14, especially in cases of drowning victims, fishing sacrifices or to enforce the traditional rules relating to water or fishing. In addition, their assistance is sometimes requested by fishermen or national authorities to ensure regional acceptance of the resource protection measures. This shows that traditional authorities still have a grip on the organization of fisheries (Toé and Sanon, 2015).

Table 14: Interventions of traditional authorities in fisheries management (Source: Toé and Sanon, 2015)

Villages	Interventions of traditional power
Moussodougou	Water Customs Sacrifices in case of drowning Participation in the sacrifice of fishermen Prohibition of cultivation on the edge of the dam Penalties for illegal fishermen Authorization given to Bozo fishermen Friday fishing ban Chair of Fishing management committee (CGP)
Tengrela	Water Customs Sacrifices in case of drowning Participation of fishermen in the sacrificing
Tiéfora	Water Customs Sacrifices in case of drowning Appointment of the Chairman of the fishermen Authorization pour augmenter the price of fish Expulsion of foreign fishermen

Legitimacy and Power Relation in Fisheries Governance

Governing natural resources involves actors' perceptions and is based on principles of negotiation that result in dynamic power relations, e.g. inclusion and exclusion of actors in resource access over time.

In the traditional system, frequently implemented before dam constructions, fishing is closely linked to the use and management of water. It requires the preservation of the resource and above all the social harmony and harmony with supernatural forces. Consequently, traditional chiefs are strong actors of this system. They allow or deny access to the resource depending on the circumstances and the rules governing the fishery. Other members of the community and non-natives were weak actors excluded from the decision-making sphere.

A state-based management system is increasingly implemented after an intense period of to dam construction starting in 1950. In this system, public waters pass under the control of the state, which replaces traditional community management with public management. The state becomes the strong player and, with its technical services, sets the legal conditions governing the organization of fishing and the marketing of fishery products. This system favours the emergence and formal organization of groups of fishermen rather than individuals. All operators of fisheries resources outside this scenario become weak actors, e.g. fishermen who have not formed into groups. The traditional authorities are also relegated to the rank of weak actors. Changes in responsibilities of actors between these management systems can be seen in Table 15.

Table 15: Relation between stakeholders before and after dam construction and in context of decentralization (Source: Toé and Sanon, 2015)

Actors	Before dam Construction	After dam Construction	During decentralization
Strong actors	Chief of village Chief of land Chief of Water Lineage owners of ponds	State State Services	State Territorial communities Organization of Civil Society (NGO, Project, Association) Traditional authorities (Chief of village, Chief of land, Chief of Water, lineage owners of ponds
Weak actors	Indigenous Population Foreign-born population	Chief of village Chief of land Chief of Water Foreign-born population	Foreign-born population

With the decentralization of power from the capital to the provinces, there is an effort to empower local authorities, civil society and local populations, especially those who directly exploit the resources. In this scheme, the state remains a strong player and favours the emergence of new actors such as fishing groups, NGOs, etc. However, the legitimacy of these new actors is often undermined by the alternation between conflictual and cooperative power relations with traditional authorities. Through increased proximity of the administration to the communities, the previously excluded legitimacies of traditional authorities are increasingly being repositioned to count among the strong players in resource governance. The local populations are absent actors and their interests are relegated to the background. Indeed, the new management structures are invested by the local authorities in order to perpetuate their authority in terms of access to and protection of the resource. Thus, they interfere in the setting of fish prices and the appointment of responsible persons in fishers' organizations such as the Economic Interest Groups (GIE). The GIE are legal organizations of fishers implemented within the German project Gestion de la Pêche dans le Sud-Ouest (GPSO) (Fisheries Management in the South-West). This project financed by the Gesellschaft für Technische Zusammenarbeit (GTZ) aimed at increasing artisanal fisheries production and experimental pond fish farming with population participation; it lasted from 1988 to 2002. In Gouandougou in the intervention zone of GPSO, during the establishment of the GIE, the presidency was entrusted to the son of the chief of the land, who was the only indigenous fisherman (MEE, 2001; Magnini, 2002; Toé and Sanon, 2015).

Despite the increasing dominance of management by the state, fisheries and natural resources management involves both public authority and traditional authorities. The role of traditional authorities and their relationship with the state oscillates through the different phases of the history in Burkina Faso depending on the political regimes. The traditional chieftains have regained much of the power they lost at the time of national independence (1960). This shift results from the increasing conviction that the national government is not strong enough to decisively govern at the local level all over the nation thus the local chiefs are stepping back into this power vacuum. In addition, different stakeholders such as the local GIE are included at the local level in decision-making regarding the access to, the exploitation and the protection of fisheries. The participation of different actors and especially the coexistence of legitimacy signify the importance for co-management of fisheries. However, the degree of involvement of these different actors and their power remains to be defined for better governance of fisheries in Burkina Faso. One attempt at generating a holistic approach is the Integrated Water Resource Management originating in the Ministry of Water and Sanitation which implies the participation of all water users. However, the plan for 2016-2030 (MEA, 2016) does not directly address fish but only some connected domains such as the protection of water against siltation, invasive aquatic plants and other obstructions in reservoirs in order to increase water quantity. Further, in general, fishing is not the most important among other water demands like agriculture, livestock or industries. Therefore, fishing is also not allocated importance in the Comité Local de l'Eau (CLE) (Local Water Committees) which as the basic bodies of water agencies at the local level contribute to the identification of problems relating to water uses and the implementation of a concerted water management.

8.2. Gender Relations and Gender Specific Strategies

Jacqueline Sow, Yaya Konaté and Patrice Toé

The severity of environmental and economic problems faced in rural areas led to a policy of hydro-agricultural development that supported the construction of dams and reservoirs. Before the commercialization of fishing, which occurred with the construction of dams and reservoirs, fishing was done primarily on rivers in a traditional manner only at subsistence level (FAO, 2008). Actors of the fishing community today are involved in the conservation, processing and marketing of fishery products in addition to fishing itself (Dao, 2014). Evidence has shown that the inclusion of actors in the entire value chain significantly reduces post-harvest losses, increases production and therefore ensures the sustainability of fishing communities (Sow, 2015). Women, accounting for more than 75% of subsistence production, paradoxically have low access to the means of production (PNG, 2009). Women face the challenge of fish availability as the major constraint during their processing activity (Sanon, 2013). Women's roles are essentially limited to post-capture representing an important link in the processing and distribution of fishery products (Sow, 2017). Different forms of processing (smoking, drying and frying) help to reduce losses after capture. For Bado *et al*. (2007), women constitute the backbone of the valorization of the catches, and in the transformation of the fish into high-quality, healthy food. For this reason, it is necessary to study and understand the role women play in the value chain and the strategies used by women allowing them to conciliate domestic and economic activities for a sustainable development of the fisheries.

Gender in the Management of Fishery Products

Konate *et al*. (2017) have shown that in the Koubri area productive activities are carried out almost exclusively by women. In productive roles, they are responsible for post-harvest activities including processing, maintenance, marketing, repair of fishing gear and equipment. In contrast, men were found to exclusively catch fish. This division of tasks in fishing activities is linked to the organization of the family, which is patrilineal and patrilocal. This strengthens man's position in moaga society and his priority access to resources. On the other hand, some women justify the separation of tasks with their heritage, if they come from other villages where there is no fishery, or that they are not used to fishing.

Women working in fish processing maintain close relationships with fishermen who supply them with fishing products. Usually, fish processors whose husband is not a fisher are forced to enter into a commercial relationship with fishers and become dependent on them to receive fishery products. These relationships are strategies developed by women to source fishery products from fishermen, as fishing poses a dangerous risk to women. They pay for nets for fishermen to keep them loyal in selling their products.

This is shown by the results of Sanou (2013) and Sow (2017), respectively. The female processors use the giving of loans to the fishermen as a strategy to maintain their production in return. The majority of processors finance certain fishing activities in advance in exchange with the fishermen. In this way, women create employment and investment opportunities for the men in the village. Ba (2006) has also recognized the importance of women's role in food self-sufficiency and in reducing unemployment and poverty in communities.

Figure 32: Photos showing the different roles of women in fishery production (from left to right: Fishing, Processing and Sale) (Source: Sow, J.) Location: Sourou

Women have increased their leverage in the fisheries market by organizing themselves within associations in order to expand their supply area with fishery products. This also gives them access to loans at the level of financial institutions, training and supervision with partners.

Women have become key players in the fishing industry through their roles and relationships (Bennett, 2005; Béné and Merten, 2008) by realizing different tasks such as administration, repairing fishing gear and selling fish (Frangoudes and Keromnes, 2008) and regarding their commitments in post-harvest activities including fish handling, sorting, preservation, processing, as well as selling (Suntornratana and Visser, 2003). They contribute to better sustainable management of fisheries through their processing techniques and commercial relations with fishermen.

Gender-Specific Roles and Division of Labour within the Household

In national strategies and programs, gender is integrated specifically or indirectly by targeting women, youth or mixed groups in activities. In recent decades, several approaches have been developed to enable women's participation in development (Dagenais and Piché, 2000; Nahavandi, 2000). In the fisheries sector in Burkina Faso, the question is recurrent. The literature abounds concerning female participation in the sector, establishing women as a link between processing and distribution of fishery products. They focus on the important role that women have played in the field of fish processing and in supporting other actors in the sector. Yet, the strategies implemented by these women in their households allowing them to conciliate domestic and economic activities, remain little known. Through qualitative examinations and interviews of actors in the Sourou Valley, Jaqueline Sow (2017) aimed to identify the roles of household members in ensuring the continuity of fishing activities and to analyze the effect of labour division on the household food and income.

Women have above all a familial and social role. They are in charge of the many domestic tasks that absorb them daily. Generally, they take care of the immediate needs of the family. Among woman’s responsibilities, the domestic or household tasks and the maintenance of the family constitute a very important part. In addition to these many domestic activities, women find time for income-generating activities to help their husbands with household expenses. Regarding specifically the fishing activity, women are usually involved in fish processing and marketing, however, they also participate more and more in the catching activity.

In the organization of activities, all members (children, adults and elderly) of the household have a crucial role to play, and very rarely solicit an outside workforce. Indeed, even the elderly play key roles as surrogate mothers to the children. They very often relieve the work of the mother by keeping the children, especially when the mother has to go out to perform external work. To this end, they allow children's mothers to escape certain obligations. They also help in fishing activities by repairing fishing tools or chipping the fish (removing the scales) contributing to the economic tasks.

As far as men are concerned, they participate very little in domestic tasks. They help women in the chores of collecting wood when the family has modern transport equipment such as a tricycle. The children's role (girls and boys) in the activities is unavoidable for the parents. Indeed, the contribution of children significantly reduces the amount of work to be done by the parents. This applies mainly to mothers (women), because by taking care of domestic activities alone, women have less time to participate in economic activities, especially fishing. The childrens support allows women to escape some of their many domestic tasks that absorb them daily and to engage in economic activities such as fishing.

Figure 33: Photos showing children helping their mothers in the fishing activity in Sourou (Source: J. Sow)

This diversification of activities appears today as a response to a fishery industry in crisis. Indeed, the increasing scarcity of fish means that, more and more, professional fishing households resort to activities other than fishing (agriculture, livestock farming, trade, etc.), although in some cases fishing income is often invested in the latter. Sow's (2015) analysis shows that the practice of income-generating activities by most of the active members of the household is a strategy implemented by the fishermen's households to cope with economic difficulties. These results are consistent with those obtained by Roussel *et al.* (2001). Their study shows that the implementation of a diversification activity is above all a coping strategy. It is one of the possible answers to the economic crisis in the fisheries sector. The results are also similar to the study conducted by Ekomo (2001) in Cameroon, which makes a comparison between single-activity households and multi-activity households. The comparison shows that a production system based on a diversity of activities preserves or improves their way of life.

The analysis also shows that women's fishing activity contributes most to household food welfare. These results are attested by those of the FAO (2012). They highlight that women spend most of their income on expenditures that improve nutrition and health. Women are therefore an important socio-economic force because of the diversity of roles they play. In this sense, Kabré *et al*. (2003) point out that the role of women in the production chain is considerable and deserves to be taken into account in fisheries development policies, on the one hand, and employment policy, on the other hand.

8.3. Value Chain Analysis for Sustainable Fisheries Management

Jacques Somda, Patrice Toé, Youssouf Dicko and Adama Fofana

In Burkina Faso, the fisheries sector employs more than 41,000 people (Zerbo *et al*., 2013). However, it still faces many constraints which threaten its socio-economic and environmental sustainability. The Directorate General of Fishery Resources estimated that 75% of capture fish are marketed fresh by wholesalers and retailers, 10% are self-consumed and 15% are processed before marketing (Bado *et al.*, 2007). In such a context (a good knowledge and control of the value chain) fish capture appears as an important step toward improving the overall technical and economic performance of the fishery sector as this is strongly linked to the quantity of fish available (Rioux *et al.*, 2010). This chapter explores the technical and economic performance of the captured fish in Burkina Faso. Specifically, it describes the ecological risks and potentials of the current value chains of capture fish from Koubri and Sourou fisheries.

Ecological Risks from Diversely Equipped and Non-Specialized Actors

In Burkina Faso, capture fish value chains can be described as highly heterogeneous or unstructured. They are heterogeneous from the point of view of the number of links they contain and by the diversity of socio-professional characteristics of the actors. In terms of links, there are short chains (fisherman-consumers), long chains (fisherman-fishmonger-processor-marketer-consumer) and several other intermediary chains. Figure 34 shows the full value chain of capture fish that is usually scattered into various chains, depending on the available business opportunity for each actor.

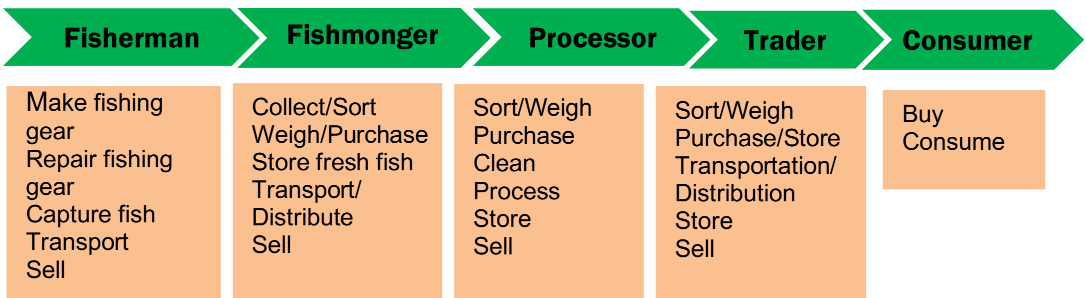


Figure 34: Full value chains of capture fish in Burkina Faso

In Sourou and Koubri fisheries, three or four types of fishermen emerge from a hierarchical, ascending classification of fishermen's socio-demographic and professional characteristics (e.g. age, experience, level of education, economic activities outside fishing, the number of gillnets, hawk nets, traps and longlines). Similar results were obtained for a typology of actors based on other links of the value chains of the capture fish.

This heterogeneity of value chains and actors is attributable to open access fisheries promoted by national policies (Bado *et al*., 2007). Access to fishing in some areas is only conditioned upon obtaining permits. This allows any actor with or without fishery-related skills to enter the fishing industry. Yet, in the absence of skills, actors can use any equipment both at fishing level and in other links in the chain. In this context, actors are poly-specific and rarely target only a particular fish species. This results in the catch of all fish species without considering the conservation status. Consequently, the lack of fish species-based specialization of actors poses another risk for species whose numbers are no longer sufficient to ensure their reproduction.

Figure 35: Photo of captured fish set to dry (Source: Dicko, Y.)

From the above results, sustainable management of fisheries in Burkina Faso will require a steady transformation of the current value chains into well organized and species-based, specialized actors. A clear and holistic policy of sustainable management for capture fisheries will be needed to structure and specialize (in terms of fish species) the actors. Such a national policy should include science-based management, monitoring, enforcement and coordination of capture fisheries in order to address the ecological issues driven by the economic performance of capture fish value chains.

Economic Potentials of Current Heterogeneous Value Chains

The fishing sector in Burkina Faso has been considered as an important economic sector both at the micro and at the macroeconomic levels. It is recognized that fishing activity easily provides income without large initial investments (Bado *et al.,* 2007). The economic analysis of the value chains of capture fish from Sourou and Koubri fisheries confirmed this. The estimated gross profit ratios suggest that all actors at all links of the value chains of capture fish are making a financial profit. However, the level of financial health depends on the link in the value chain and the socio-professional characteristic of the actors (Dicko, 2018; Fofana, 2018). Thus, fishermen showed the highest gross profit ratios[1], which are between 82% to 93%. For fishmonger, the estimated ratio ranged from 4% to 19%. For processors, who are mainly women, the estimated ratio was between 9% and 19%, and the traders are earning between 12 and 26 FCFA for each FCFA invested. These figures are higher than reported by Kaboré (2014) for horticultural crops in the Nakambé watershed and can be justified by the low cost of investment required for equipment.

These results indicate that actors in capture fish value chains are making reasonable profit on sales. This partly explains why the capture fisheries sector is still attractive for actors who do not necessarily have fishing skills and experience. Although the attraction of an activity is an opportunity for its development, it can also quickly become a constraint if the entry into the activity is not well managed. This is particularly important at the level of the "fishing" link where high attractiveness can lead to overpopulation of experienced fishermen, which in turn will quickly lead to overfishing. This attractiveness can also increase in the number of inexperienced fishermen leading to the use of unsustainable fishing gear.

The Need for an Integrated Ecological and Economic Management

The promotion of sustainable fisheries management could be part of the pro-poor and gender-balanced strategy in rural and periurban areas in Burkina Faso. The sustainability, as well as the development of the value chains of capture fish, is important to increase income for the actors while also increasing the supply of domestic fish to a growing urban population. The current high financial profitability

[1] Gross profit ratio (GP ratio) is a profitability ratio that shows the relationship between gross profit and total net sales revenue. It is a popular tool to evaluate the operational performance of the business.

can only be sustainable if the ecological aspects of the fisheries are fully integrated into the value chains development.

This implies the development and implementation of the ecosystem-based fishery management, which is an integrated ecological and economic approach. Such approach is urgently needed if the objective of fishery development is to sustainably reduce the current deficit of domestic fish supply in Burkina Faso.

9. Aquaculture: History and Potential

Laura Hundscheid, Vincent Paul Sanon and Raymond Ouedraogo

Aquaculture is the “rearing and production of fish and other aquatic animal and plant species under controlled conditions” (Somerville *et al*., 2014). This involves measures for increased production such as feeding, control of environmental parameters, protection from predators and disease as well as regular stocking. In Sub-Sahara Africa (SSA) the predominant fish species cultivated in aquaculture are: *Clarias spp*, especially *Clarias gariepinus* and *Tilapia spp*., especially *Oreochromis niloticus* (Satia and FAO, 2017). In West Africa, Nigeria and Ghana are by far the biggest producers of fish from aquaculture as well as from capture fisheries. All other states have a significantly lower output, with Togo and Burkina Faso having the lowest quantity from aquaculture and capture fisheries, respectively. Their share of fish from aquaculture of the total quantity produced ranges from 0 to 2% (see Figure 2 on page 10), while about 14% of Ghana’s and 30% of Nigeria’s fish quantity produced come from aquaculture systems (FAO, 2018).

As fish is regarded as playing a “special role in nutrition and health” in developing countries, a better fish supply should be pursued (Satia and FAO, 2017). Fish is recognized as a “major nutrient dense animal source food” for a significant part of nutritionally vulnerable people and exceeds the share of most of terrestrial animal foods. Therefore, fish contributes to SDG 2 (United Nations Sustainable Development Goals) to “end hunger, achieve food security and improve nutrition” (ibid). As Burkina Faso is one of the least developed countries, worldwide famine is a recurrent issue. About 44.5 % of five-year-old children and 13% of women of pregnancy age are affected by chronic malnutrition (DGPSA, 2007). This makes food security a core issue of national development policies and strategies. As aquaculture has become the fastest growing food production sector worldwide, its contribution to food security is of special concern (Satia and FAO, 2017).

The loss of habitats and human pressures, which are strongly enforced by the enormous population growth, have led to a decline of the total fish population, biodiversity and average fish size in Burkina Faso (Meulenbroek, 2013) and consequently to reduced fish catches. The national demand cannot be covered by domestic fisheries and aquaculture, so currently more than 80% of the consumed fish is imported (FAO, 2018), mainly *Tilapia spp.* from China, which has created a strong market dependency on fish imports (Satia and FAO, 2017).

Aquaculture in Burkina Faso has a weak historical performance and is rarely developed up to now. The tradition or history of aquaculture in Burkina Faso was described by Miller (2006) as a simple form of aquaculture which had been implemented during the dry season for many decades in Burkina Faso and neighboring countries (Mali, Niger, Benin) to extend the fish availability for local communities. In doing so, fishes from lakes, rivers or reservoirs are caught and kept in marshes. Methods used include collecting, holding, transporting and stocking fingerling fishes, combined with some feeding of fish in ponds and small lakes. The species involved include *Clarias spp*., *Heterobranchus spp*., *Synodontis spp*.

The National Adaptation Plan (NAP) established in 2011 set a focus on the development of aquaculture by implementing best practices (FAO, 2018). The SN-DDPA (National Strategy for Sustainable Development for Fisheries and Aquaculture by 2025) refers to a targeted increase of domestic fish production by aquaculture by 40% per year and estimates at 110,000 tonnes of fish as the current possible production of aquaculture (Ministère des Ressources Animales et Halieutique, 2013). International literature by the FAO states that Burkina Faso would have a potential to increase its aquaculture production by 16% singularly based on extensive integrated rice and fish production. This would be a value of 712,135 US$ and 579 estimated new farm jobs. The calculation was done on the basis that 15% of the irrigated rice area in south-western regions of Burkina Faso would be integrated with aquaculture with an annual production of 250kg fish per ha (Miller, 2006). Aquaculture represents a suitable possibility for the provision of a secondary income source and thus to reduce overfishing. In addition to the reduction of overfishing, aquaculture can contribute to the recovery of fish populations by producing juvenile fish for restocking, if complementary protection measures are adequately planned, implemented and monitored (Hundscheid, 2019). However, the current estimates show that this ambitious target can not be achieved in the coming year, unless fundamental measures are taken.

The sector of aquaculture is of special interest to improve working conditions for women, since the field has just started to develop, and gender barriers have not been established yet (Melcher *et al*., 2019**,** Konate, 2019). Women can be integrated in the whole valorisation chain and through training opportunities right from the beginning. In other SSA countries, aquaculture already provides working opportunities for women. In SSA 34% of employees in the aquaculture sector are female. Especially in the islamic republics of Gambia and Mozambique the proportion of women in this sector is very high with over 50% (Satia and FAO, 2017).

Figure 36: Scenes from the market of Koubri where women are processing and selling the fish. (Source: P. Magnuszewski)

By conducting interviews in Burkina Faso three main constraints blocking the development of aquaculture were identified:

- An overall shortage of financial means, in the private sector for farm construction and maintenance, in administrative institutions to develop and implement adequate management strategies, in scientific institutions to finance advancing research projects.

- A lack of policy implementation, which is reflected in a lack of support and unreliability of subsidies, the absence of training opportunities and the lack of basic infrastructure. Besides the shortage of financial resources, the missing decentralization of management institutions in the sector, as well as the frequent shift of ministries, the so called "institutional nomadism" were identified as root sources for this problem of implementation. This point is similar to the described constraint for the development of sustainable fisheries management.
- The lack of profitability, which discourages private operators to start aquaculture. This is mainly driven by two factors. First, the quality of available fingerlings and fish feed, which only allows low production rates. And second, the low market price for fish, which is dominated by cheap imports from China and neighbouring countries.

Regrettably, no deep investigation on economic aspects of aquaculture in Burkina Faso has been undertaken so far. If the quality of fingerling fishes and fish food is seen as problematic for the development of aquaculture the overall question is: Which aquaculture systems are suitable for Burkina Faso? Extensive to semi-intensive systems do not require very high quality and expensive inputs and as such may also be available to peasants rather than only to agribusiness men.

Currently about ten governmental fish farms have been created and are spread throughout the national territory, with the purpose of serving as practical examples of fish farms, producing fish for restocking and private aquaculture farm development as well as to fuel research and training. Unfortunately, much remains to be done for these farms to be effective as most are poorly designed and managed.

Figure 37: In the governmental aquaculture farm of Bazèga, some fish ponds cannot be filled with water (Source: R. Ouédraogo)

Nevertheless, the development of aquaculture is a priority in the national strategy for fish resources. For this reason, since 2002, at national level an entire technical directorate has been dedicated to aquaculture. From their records, about 200 private fish farms are said to be existing but their production is unknown at the moment. Most are located in the suburban areas and large hydro-agricultural reservoirs such as Bagré and Sourou.

When establishing aquaculture systems, it is important to consider ecological sustainability, since intensive cage systems pose high risks on water quality through nutrient input and on wild fish species through disease exportation and genetic pollution (Froehlich *et al.*, 2017). Ecological aspects must be sufficiently taken into account in the planning of aquaculture systems in order to protect the ecosystem and ensure long-term use of the natural resource. It is generally recommended to establish aquaculture on small or medium scale, including small or medium enterprises and subsistence-based systems (Akpabio and Inyang, 2007; Miller, 2006; Satia and FAO, 2017). Large-scaled systems should be avoided, due to ecological threats as it would be associated with excessive investment and risk and would also exceed the capacities of the economic infrastructure (Miller, 2006; Satia and FAO, 2017). The highest impact for poverty reduction is also posed by smallscale artisanal farm systems mainly by its strong indirect poverty links improving food security and livelihoods of the poor (Kassam and Dorward, 2017). Figure 38 highlights which constraints and potentials should be considered when implementing aquaculture systems.

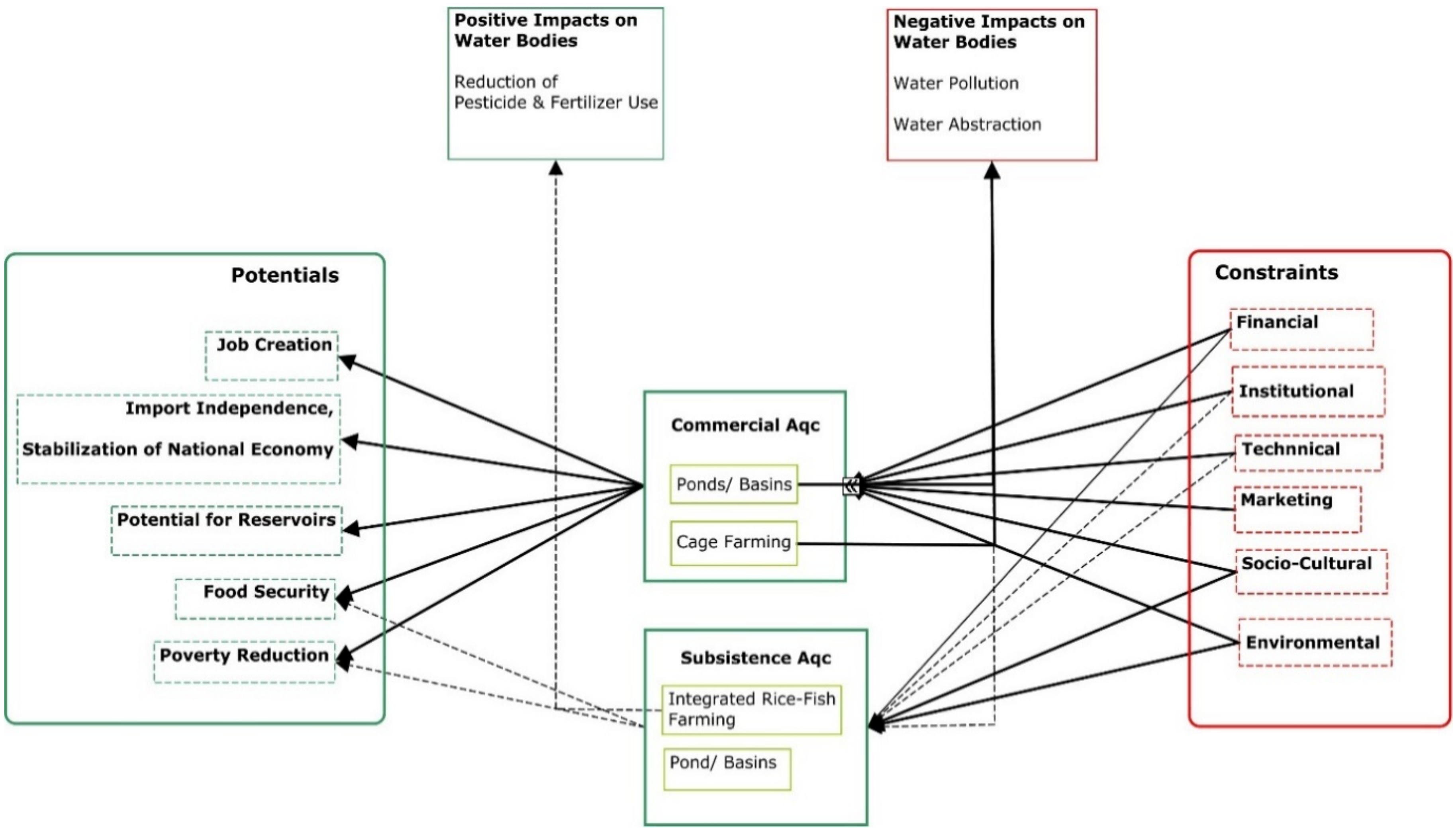


Figure 38: Constraints and potentials for the development of aquaculture systems on commercial and subsistence level and its impacts on water bodies. Based on the interviews & literature (Source: Hundsheid, 2019)

10. Strategic Simulation and Scenario Workshops

Gabriele Slezak, Piotr Magnuszweski, Michalina Kulakowska and Charlotte Voigt

The development of scientific tools such as monitoring instruments, mathematical simulations and statistical analysis of trends is vital to support decision-making for sustainable resource management. However, even a skillful implementation of these tools may not be sufficient to ensure that sustainable decisions are being met as the interactions of social, political, cultural and psychological factors influence the success or failure of policy implementation by resource users and communities. In order to study and observe such interactions in Burkina Faso, a strategic simulation was conducted with a variety of stakeholders within the SUSFISH Projects. This exercise also allowed the creation of a more comprehensive understanding of sustainability beyond the few prominent and obvious phenomena.

Strategic social simulations or policy exercises combine interactive scenarios, role-playing and game-like mechanisms in order to provide a more realistic environment to study and understand the challenges specific stakeholder face. Through this, simulation can also provide potential solutions or show new forms of collaboration necessary for problem analysis and is also a learning possibility for all actors involved or observing. Strategic simulation can provide an opportunity to retain information quickly and gain intuition about real decision making. Variations of such exercises have been used in topics such as: international climate change management (Parson, 1995), European climate policy (Haug *et al.* 2011) or the social aspects of river floodplain management (Stefanska *et al.,* 2011).

The idea was to develop a simulation, which was tailored to the special needs of the water and fisheries management sector in Burkina Faso. The development process was based on results of the former project and on the feedback of two workshops held in Bobo Dioulasso (January 2018) and Vienna (September 2018). While the first was focusing on the introduction of a simulation approach, the latter was a simulation conducted under guidance and leadership of the Center for Systems Solutions (CRS) and collected the input of representatives from partner organizations. This workshop in Vienna was designed to introduce and test the methodology, presenting an overview of the process for application with a larger group in Burkina Faso. In a final 2 days workshop in Ouagadougou (February 2019) we could mobilize various experts and stakeholders to participate in discussing and conceptualizing desirable future pathways for the Nakambé basin as an example. Results from the first simulation were then expanded with the larger group of stakeholders.

The simulations were designed to 1) create an overview of the current situation, identifying important factors and challenges of socio-enviro-economic situation in the river basin and based on this 2) develop 'business as usual' and 3) desired potential pathways in the future. Parallel to the simulations, observers were tasked in noting extent and quality of the interactions in the discussions. In a final step the game based social simulation was adapted concerning the feedback of stakeholder participation and will serve as an open source tool for actors and policy makers in the Burkinabe fisheries and water management sector.

Characterizing the Current Situation

Visual aids, maps and cards representing entities, processes and indicators were used in order to facilitate discussions. Participants were asked to use these tools to discuss and depict the situation of areas outlined on the basin map. Participants were also able to indicate smaller areas which require a more detailed description. These were often cities, specific industrial or agricultural areas and reservoirs. Each of them was then classified according to land-use categories. Using separate posters for smaller areas, further description was possible indicating for example present fish families, specific conflicts or infrastructure such as dams. All participants were encouraged to move the cards around the map according to their expertise and also discuss and add factors which may be missing.

The current situation was then reflected onto a systems diagram or 'causal map' that had been prepared beforehand. On the causal map factors that could be important to the Nakambé basin and fish harvesting in the region were grouped according to previous research and input from previous tests and workshops. Participants were asked to rate the level of influence each factor had and its correlation with other elements. This enabled a discussion of trade-offs and interdependencies which may not be directly linked to fish harvest at the first glance with other more obvious factors. Causal diagrams were created for the three focus areas: Water & Environment, Food & Fish and Economy & Energy.

Starting with the indications of human wellbeing such as: health security, food security, gender equality, economic inequality and income levels, the participants determined that these indicators directly affect a populations capacity for development. Subsequently, indicators of development such as agriculture, urbanization, mining, water infrastructure and deforestation amount to increasing anthropogenic pressures affecting the size of natural fish habitats, natural life cycles, and hence fish harvest. A reduction of fish harvest will in turn affect the food security and wellbeing of the population. The extent of influence from each indicator was determined via self-assessment, with 5 being the highest and 1 the lowest influence. These causal maps of interdependence allowed for a systemic look at problems, resisting the traditional pattern of determining one key variable to describe a problem (Slezak *et al*., 2020). Through the different parties involved in the workshop different perspectives and experiences could be incorporated leading to a co-creation of knowledge.

Figure 39 shows the causal map summarizing results from the different groups of the strategic simulation.

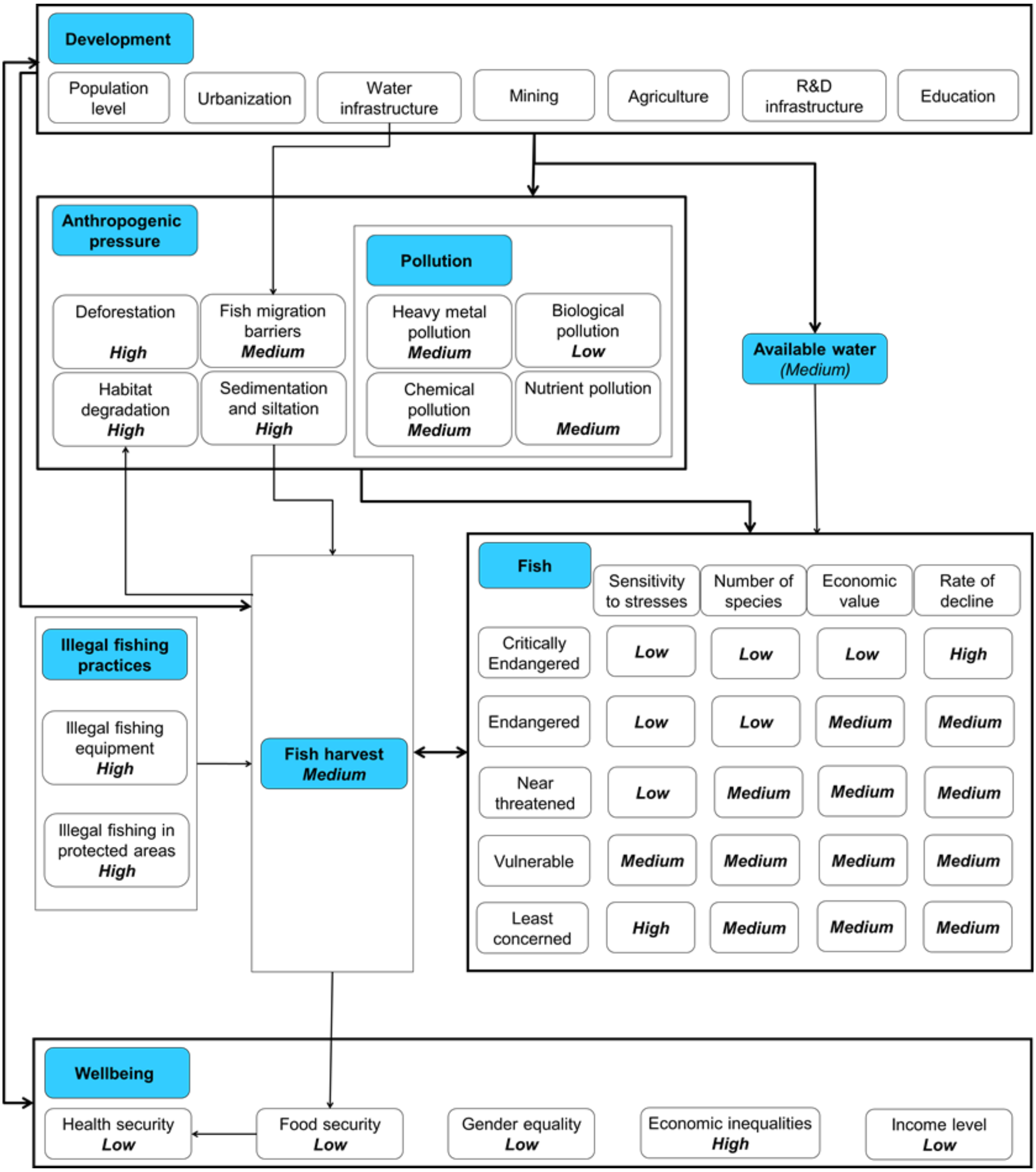


Figure 39: Causal Map from the strategic simulation. Arrows show interdependencies between factors from previous research in the Nakambe Basin and Burkina Faso grouped into environmental and socio-economic clusters. "Low","Medium" and "High" represent the extent of influence of each factor. (Sanon et al.*, 2020)*

Developing Visions and Future Pathways

Following the description of the current situation the participants were tasked with creating visions of the future and their corresponding pathways. Using the same cards changes (increases, decreases, removals or addition of new cards) could be made to the map. Risks, opportunities and challenges were also marked on the map. Three different narratives were developed, each with an emphasis on one of the three focus areas.

Figure 40: Stakeholders working on future pathways in groups (Source: Piotr Magnuszewski, 2019)

Nakambé Vision-priority Focus on Water and Environment Sector

An increased protection and conservation of water and environmental resources can only be achieved with substantial support from the responsible ministries. As named by the participants these are: Ministry of Animal and Fish Resources, Ministry of Water Resources, Ministry of Environment, Ministry of Agriculture.

Additionally, investments are necessary in the cleaning of the waterbodies and reforestation of shorelines and restoration of special buffer zones. In order to reduce illegal and off-season fishing attempts should be made to increase the support for private owners and small businesses contributing to local enterprises and the community’s economy. In this fish farming as well as related activities should be popularized. A focus on education is also vital to increase awareness and foster dialogue between conflicted stakeholders.

Nakambé Vision-priority Focus on Food and Fish Sectors

With a focus on food security without depleting natural fish stocks, investments in water and fish infrastructure are necessary. Negative impacts of fossil fuel related industries on fish stocks should be limited by investing in green energy sources. This can be done by using existing infrastructure (hydropower from existing dams) or creating new dams which would also allow for benefits in agricultural production by increasing irrigation possibilities. All energy sources should be considered in order to limit the negative impact of hydropower on fish populations. Fish population control can be complemented by stocking practices or the creation of new spawning grounds. Substantial investment is also necessary in assuring high water quality by limiting the negative impacts through sedimentation, salinization and heavy pollution. This will also benefit the health and wellbeing of the population as reservoirs are frequently also used for drinking water. An improvement of the education system will also enable new opportunities for research and development and foster innovation in the regions. Most important for this pathway is increased awareness of problems and challenges in the basin, technical knowledge and soft skills such as negotiating, leadership and teamwork.

Nakambé Vision-priority Focus on Economy and Energy Sectors

Placing economic growth at the centre of sustainable development would mean a focus on maintenance and rehabilitation of existing dams. Regarding the development of new dams, special precautions need to be met as these can have negative impacts on fish populations and thus on the food security and economy of the basin as well as all of Burkina Faso. New dams should be equipped with fish passage technologies to limit the effects on fish reproduction, biodiversity and possibly enabling a larger fish harvest. The consideration of international experiences can bring ideas. These investments should also be considered for existing infrastructure. The creation of a plan for water delivery to agriculture and the reform of existing channel irrigation to more efficient drip irrigation are necessary to aid farmers. The production of more sustainable energy can be achieved by diversifying energy sources to secure a steady flow of energy to household and production facilities. Private sector and the energy sector should seize the opportunities provided by solar energy production to reduce the dependence on fossil fuel-based energy sources. Rural exodus as a result of to the development of open pit mining was identified as a key challenge. Consideration should be given to an investment in industrial mining and a recultivation of open-pit mines along with employment policies targeted at youth employment to adapt newly acquired land to productive agriculture. For the development of energy and economy, education was found to be an important factor. A focus should be given to sustainable development and natural resource management in order to raise awareness of the issues and challenges of the basin, while attention should also be given to family planning in order to stabilize the birth rate and health of residents.

Figure 41: Factors placed on the Basin map in the development of the Economy & Energy future pathway (Source: Piotr Magnuszewski, 2019)

Summary of the Process

In summary, the Nakambé strategic simulation provides a platform for interaction in transdisciplinary development research. In development activities, it is often a challenge to discuss and exchange experiences between experts and local stakeholders, through moderated and guided discussion rounds the simulation allowed for fruitful exchange and mutual learning. Through this a broader understanding for interrelations between sectors was brought up highlighting the complexity of sustainable decision making. Important for the use of such a tool is the training of moderators as these have a high influence on the productivity, direction and character of the discussions. The toolbox developed in the SUSFISH Project by Centre for Systems Solutions is provided as open access by the SUSFISH Consortium in order to encourage a wider use of such instruments.

11. Synthesis: Conceptual Modelling

Jan Sendzimir

There are multiple entries to the road to food security through sustainable fisheries in Burkina Faso. That security can be realized through regenerating and protecting the natural productivity of aquatic ecosystems and their surrounding landscapes. It can also be realized by technologically boosting fishery productivity through aquaculture. Security can be boosted by improvements to the technologies and institutions behind fish processing and trade, e.g. the so-called "Value Chain" – the commercial links that bring fish and fish products to market. And, finally, it can be reinforced by catalyzing the greater potential of a wider swath of society, e.g. women, through changes to social, political and cultural institutions.

This book addresses all four paths, and this section attempts to develop an overview of fisheries sustainability by summarizing the lessons learned in each. It then uses systems analysis to look at some of the mechanisms or interactions that are key to understanding the barriers to sustainability along each path, as well as the interactions that link the four paths on the road to fisheries sustainability.

Sustainability research often begins with clearly identifying important trends in how the environment and society are changing. These can be economic growth or environmental deterioration (or recovery) among many other things. The search then goes deeper to define patterns of interactions that might generate such trends of concern. These causal patterns might be simple couplings or complex webs of interactions, but of particular concern are cyclic or circular patterns of causation, because people commonly assume causes only occur in chains. Linear causation does indeed occur, but our tendency to assume linearity can blind us to cycles. This is especially important when such cycles can drive sudden and surprising changes or unstoppable surges of growth or decline.

Systems thinking has emerged as part of efforts to develop a science that identifies and analyzes how patterns of groups interactions affect the way the world changes. Causal loop diagrams (CLD) are a graphic language developed to aid the search for such patterns, circular ones (or loops) in particular. This section uses CLD to show hypothetical patterns of interaction that may influence the trends identified as important to fisheries sustainability in Burkina Faso.

The simplest element of a CLD is an interaction that hypothetically links a pair of variables. Such an interaction is symbolized by an arrow, which also indicates direction. That is to say, if variable A (at the origin of the arrow) changes first, then variable B (at the receiving end of the arrow) will respond with a change. The "polarity" of the interaction indicates whether both variables change in the same direction or in opposite directions. In the former case, an increase or decrease in variable A is matched by the same change in variable B. This polarity is symbolized by the + sign. If the variables change in opposite directions, e.g. if variable C increases then variable D decreases (and visa-versa), and that is symbolized by the – sign.

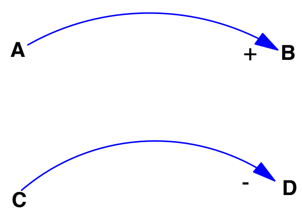


Figure 42: Link Polarity in a Causal Loop Diagram interaction

A "causal loop" is shown where a cause flows from one variable to the next around a circle in a chain of interactions. Human societies have noted such circular patterns of behavior for millennia, enshrining them in our lexicons as "vicious cycle", e.g. cycles that repeatedly generate deplorable results or "virtuous cycle", e.g. cycles that perpetuate laudable results. Figure 43 illustrates an example of both kinds of feedback loop. Starting on the right side, *Fish Restocking* (artificially adding a new cohort of fish) causes the *Fish Population* to rise. This usually results in a larger *Fish Harvest*, generating larger *Profits,* which in turn can be reinvested in increasing *Fish Restocking*. Such loops are called "positive" or "reinforcing", because each causal link reinforces the next, and it is symbolized with a circular arrow with the letter R at the center. This can sustain an upward or a downward spiral unless checked or "balanced" by another interaction or set of interactions, such as a "negative" or "balancing" feedback loop. Such a balancing loop is illustrated in Figure 43 with a circular arrow with the letter B at the center. It might run as follows: as *Fish Population* increases, so does *Fish Density.* This often leads to an increased *Predation Rate*, thereby decreasing the *Fish Population*. Note: that as one completes the circuit of a loop, the trend will continue as it started in a Reinforcing Feedback Loop, i.e. if it starts by increasing the next variable, then the last variable in the loop will increase. However, the trend will go in the opposite direction if it is a balancing feedback loop. An initial rise will end up in a decrease, or vice-versa.

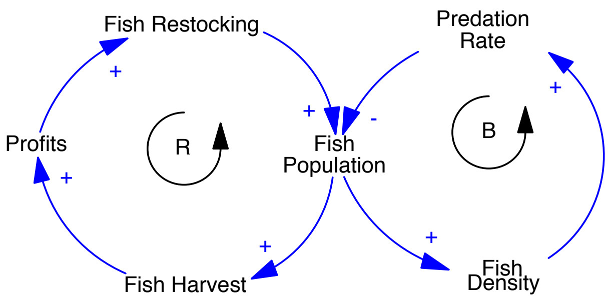


Figure 43: A causal loop diagram depicting both reinforcing and balancing feedback loops

Finally, besides influences or causal links, CLD can represent stocks (storages of matter or collections of things) as well as flows between stocks. Stocks are represented by squares, and the rates of flow between them are symbolized by arrows with an hourglass in the middle. For example in Figure 44, all the fish less than one year of age in a population could be considered *Fish Cohort Year 1*, and those that survive to Year 2 are called *Fish Cohort Year 2*. The more fish in *Fish Cohort Year1*, the greater the survival (or flow) of fish to reach Year 2, as indicated by the arrow linking the Year 1 stock with the flow labelled *survival rate*.

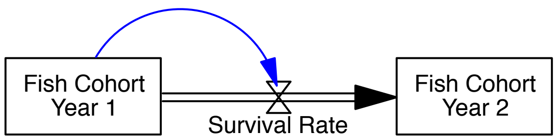


Figure 44: Flow (surviving fish) between two stocks – Fish cohorts for years 1 and 2

Working Landscapes - Fish Regeneration Trap

The second half of the twentieth century saw a massive expansion of a hydrological network of reservoirs in Burkina Faso, both as a hedge against drought and a driver of agricultural and rural development. Along with these benefits, a host of long-term threats to the integrity of aquatic ecosystems emerged. Predominant among these are overfishing, intensive agriculture and sedimentation, but a diversity of other threats arose, many as by-products of a growing economy driven by a burgeoning human population. The range of these threats includes hydrological, chemical, morphological, ecological, land use and land cover, and blockages to hydro-connectivity among many others (see Section 3 on page 28). They emerge from the highest to the lowest elevations of each river basin, but their strongest footprint is with aquatic ecosystems and their immediate surrounding uplands.

All of these threats and pressures have combined to suppress the diversity and productivity of Burkinabe fisheries. Aside from a very few protected aquatic ecosystems, almost all fisheries exhibit a small fraction of their productive potential. Our understanding of how these factors combine to suppress productivity is limited, but it has exposed a salient challenge: no configuration of the current management regime can reverse the decline of productivity in aquatic ecosystems under current ecological and socio-economic conditions. Burkinabe fisheries are caught in a "Regeneration Trap" – and any strategy to restore natural productivity will only marginally change things if it does not address this. This section examines that trap from a systems perspective to look for patterns of behavior that are critical to how such a trap emerges and is reinforced. These could be critical points of intervention for escaping the trap that future research and experimentation might reveal.

The drive to boost food security by developing other pillars of fisheries, for example aquaculture, in Burkinabe society only increases as the prospect of restoring fisheries productivity in natural aquatic ecosystems declines. That prospect of such restoration now appears very dim indeed. Fishing appears too intense to allow the establishment of breeding populations of sufficient fecundity to outproduce the fishing harvest levels. While fish species often exist as communities of diverse age cohorts, for the sake of simplicity Figure 45 depicts only three cohorts, each arbitrarily assigned to represent one year's production. While arbitrary, this 3-cohort depiction may not be so inaccurate. Fish markets seldom offer fish of sizes reached in years 2 or 3 (see Figure 35 on page 85). One explanation is that post-harvest residual fish populations are too small in number and too small in size to produce enough offspring to exceed the following harvest and thereby build a more numerous, resident population of larger, more productive adult fish. Fish production of eggs and sperm increases disproportionately with body size (Barneche *et al.*, 2018), sometimes exponentially. Not only might an, elder, larger female produce 10 000 times as many eggs as a much smaller first year fish, but her eggs would have much higher survivability because they contain energy levels more than an order of magnitude greater that do smaller females of previous year cohorts.

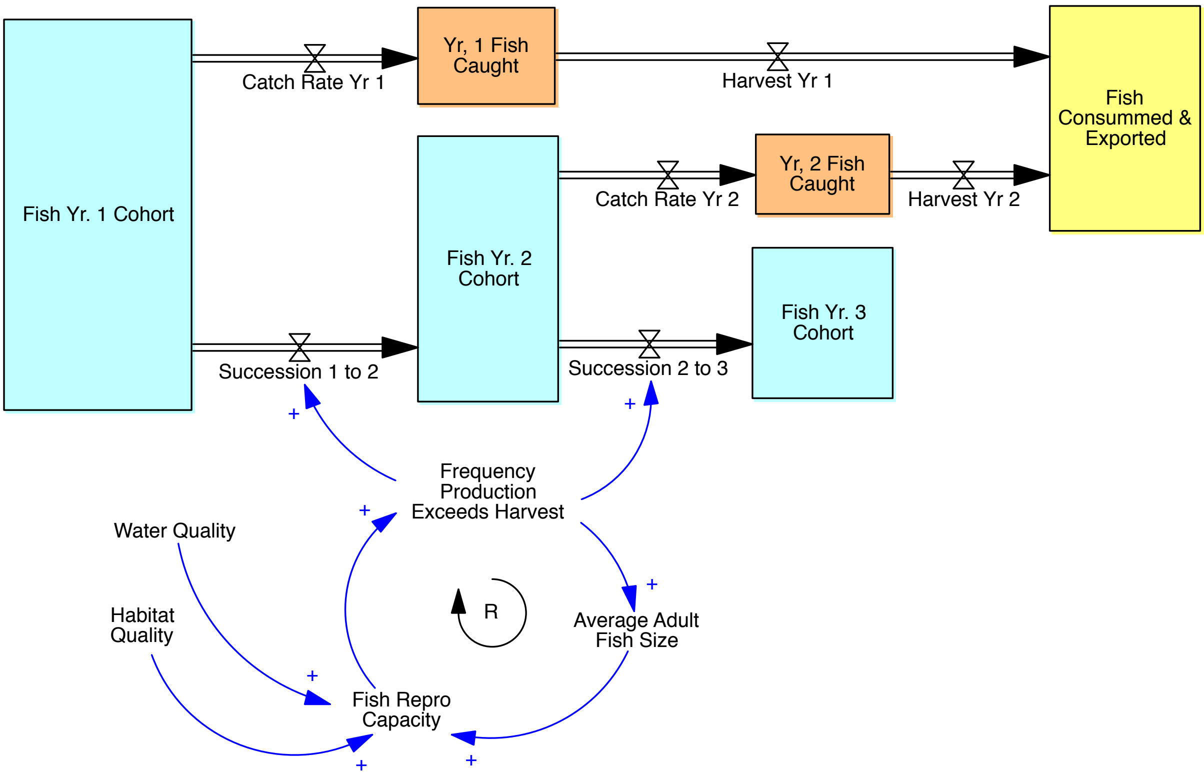


Figure 45: Fish populations regeneration potential trapped by overfishing in Burkina Faso

In summary, excessive harvest levels appear to create a ceiling preventing most fish species from advancing to the second- or third-year cohort. This is a vicious cycle reinforced by very small average adult body sizes that can never outproduce harvest levels. In addition to the harvest ceiling that traps fish age and size to the first-year cohort, fish reproductive capacity is further checked by environmental impacts to water and habitat quality. In the former case, sedimentation and agricultural run-off lower water quality. In the latter case, removal or damage to habitat structure leaves fewer opportunities for fish to seek shelter, forage and reproduce.

Agro-Industry - Barriers to Aquaculture

The art and science of artificially boosting fisheries productivity in both natural and synthetic habitats is broadly known as aquaculture. It has emerged over centuries elsewhere but has only been tested and developed in its more modern, technological forms in Africa over the past 50 years. Prior to this only very simple forms of aquaculture were attempted during the dry season in Sahel nations like Burkina Faso, Mali, Niger and Benin to extend the availability of fish to local communities.

If one measures its success as aquaculture's proportion (percentage) of all fish consumed, then in West Africa the success rate varies from 30% (Nigeria) down to 14% (Ghana) and as low as 0 – 2% (Burkina Faso and Togo). In the near absence of aquaculture, the 20% contributed from capture fisheries in BF must be supplemented by 80% imported from abroad. Fish imports, therefore, are filling a gap in local fisheries productivity. This arrangement satisfies current protein demand, but as population increases drive demand higher, Burkina Faso appears increasingly vulnerable to external food sources, and hence the reliability of global trade. The rising uncertainty from turbulence in nature (climate) as well as a fragmenting political economy suggests that food security in Burkina Faso rests on a risky foundation.

Currently, efforts to increase food security focus mostly on aquaculture, since boosting the productivity of capture fisheries appears an unlikely, or, if possible, a very expensive and long-term scenario. Aquaculture looks like a good potential labor opportunity for women, because the industry is young and developing, so no cultural norms have been set yet. However, despite a National Plan in 2011 officially targeting a 40% annual increase in aquaculture production, such gains look unachievable. The National Plan would expand the number of reservoirs. This boosts production in the short-term but ignores longer term solutions of increasing the reproductive capacity of existing aquatic ecosystems by managing land use impacts that degrade the quality of water and habitats. Such enhanced management also addresses the potential for aquaculture to pollute the environment as it increases productivity. The capacity for environmental assessment must be enhanced to anticipate impacts as well as to monitor the performance of new and existing land uses.

It is generally recommended to establish aquaculture on small or medium scale, including small or medium enterprises and subsistence-based systems, which avoid the ecological threats and investment risk inherent in large-scaled systems. The highest impact for poverty reduction is also posed by small-scale artisanal farm systems mainly by its strong indirect poverty links improving food security and livelihoods of the poor. The following section examines some of the key elements that block the introduction and development of Aquaculture.

The salient question for Burkina Faso is what barriers prevented it from successfully establishing aquaculture when its neighbor to the South, Ghana, already realized 14% of fish consumption through aquaculture. One barrier frequently mentioned is lack of investment, both for the training needed to raise the skills of aquaculture production as well as to monitor environmental impacts.

Figure 46 suggests this barrier is a causal loop driven by the fact that inexpensive foreign fish imports keep fish prices too low to attract investors to risk aquaculture start-ups or even to do research to develop and improve the technology. The poor prospects of profitability due to low production rates of available varieties of fish fingerlings points up the need of such research and development. In sum, the cycle is reinforced by two shortfalls (shown in red). Fish production in Burkina Faso falls far short of demand, allowing foreign imports to dominate, and foreign domination holds prices below levels that might spur the investments that would establish the industry at levels competitive with global actors.

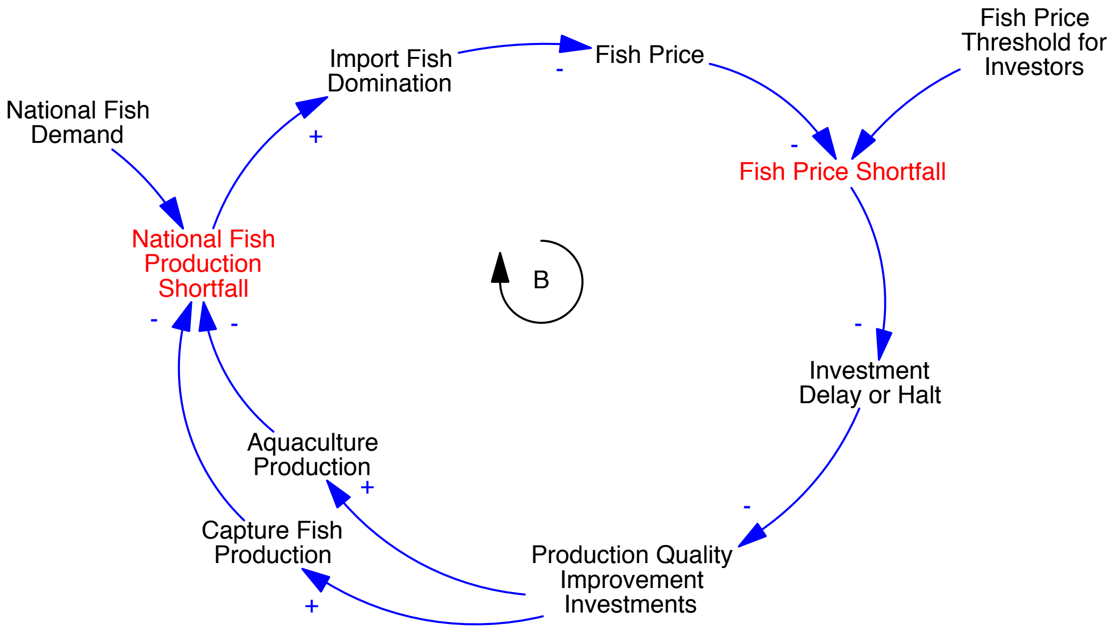


Figure 46: Fish Investment Trap

What factors enable foreign actors (especially China in this case) to ship fish over 12 000 km and deliver them cheaper than fish products locally produced in Burkina Faso? One set of explanations revolves around subsidies driven by trade policy that strongly emphasizes export. For 25 years the People's Republic of China's economy has grown faster than most economies based on export, and in 2013 launched an initiative (The Belt and Road Initiative, aka the Silk Road) to massively invest in infrastructure and establish a global trade network across 152 nations. This Chinese strategy is a national priority, enabling state expenditures to subsidize and lower export costs. As a result, China is one of the dominant trading partners of almost every nation in Africa and in many other nations globally. Coupling this Silk Road initiative with global subsidies in excess of 500 billion dollars for fossil fuels, shipping costs are at historic lows, making export over long distances possible. The income earned and secure establishment of its global trade network has reinforced this policy, and its attendant subsidies, in a feedback loop that reinforces and boosts each variable in the circle (Figure 47).

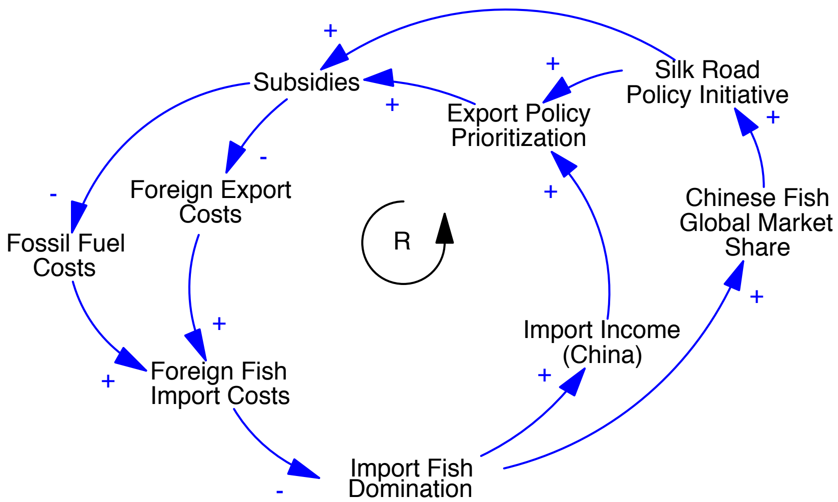


Figure 47: Chinese Export Policy influence on fish imports in Burkina Faso

Over the past few decades fish imports have risen to provide almost 80% of domestic consumption. At one time in mid-20th century, Burkina Faso produced almost all fish consumed locally. What factors have driven fish demand to exceed local production capacity by four-fold? Population growth rates, among the world's highest, are obvious candidates, but how that meshes with migration, urbanization and economics raises interesting questions (Figure 48). The burgeoning growth of major cities in Burkina Faso is fed in part by out-migration from rural communities whose economies cannot sustain populations beyond certain levels. If one ignores migration out of Africa, so far it seems the national and even regional system can absorb such high growth levels. In-migrants to cities expand the labor pool and their demand for resources spurs the urban economy. Food demand will rise with the sheer number of people multiplied by the increased buying power of a larger, more integrated economy. What is not reflected in these hypothetical models is the role women play as middle-persons in the value chain of fisheries in structuring demand for fish. The agency of women in driving the uptake of foreign fish imports is addressed in the section on Gender.

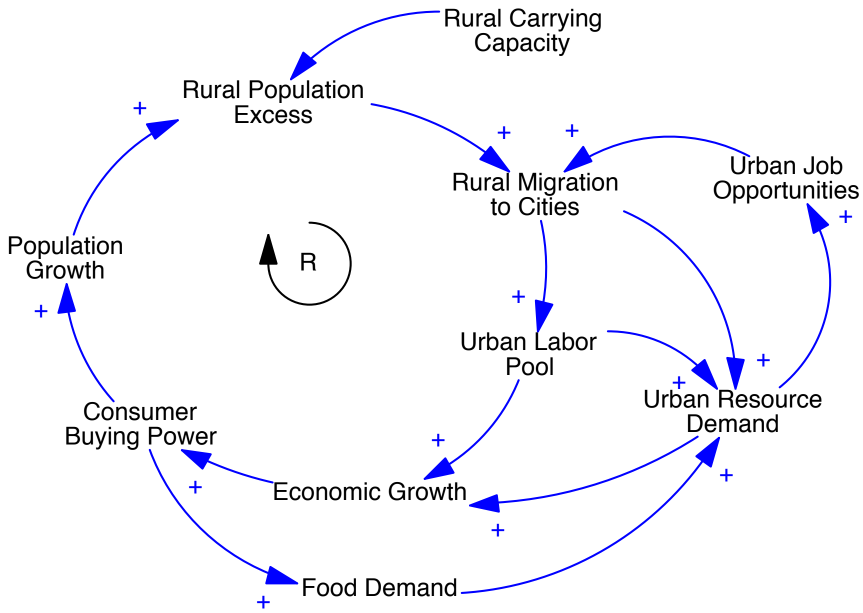


Figure 48: Urban Growth Drives Food Demand Increases

Commerce - Value-Added on the Fish Production Chain

Food security is about more than simply guaranteeing the quantity of food that reaches the consumer. Food quality is vital to overall health and is especially important for the physical and mental development of children. In the latter case, protein intake in the first decade of life is critical to cognitive development. Fish provide a critical contribution to protein intake in Burkina Faso, so sustaining the quality of fish from capture to consumer is an important priority for food security policy.

After initial capture and harvest, quality or value is sustained or added to fish in a series of processes known as the "Value Chain" as more fully described in Section 8.3 on page 83. Sustaining quality is critical in a perennially warm climate where microbes can cause rapid deterioration of food quality. To maintain quality, the chain must swiftly deliver its goods, since some 75% of capture fish are marketed fresh by wholesalers and retailers. Of the remainder, 10% are self-consumed, and 15% are processed before marketing.

Fish demand should continue to rise, driven by the needs of an increasing population with increased buying power in an expanding economy. With the increasing concentration of Burkina Faso's population in urban centers, the average distance from fish capture to consumer increases. That is to say that as demand for fresh fish for more local rural consumers declines as a percentage of total consumption, the value chains must lengthen. Longer value chains require higher standards (technology, policy), and hence greater expenses, to sustain quality delivered. The drive to increase the performance of national capture value chain is only increased by competition with global actors like China, from which 80% of fish consumed in Burkina Faso originates.

However, the challenge of increasing and guaranteeing food security is about more than simply modernizing value chains with better technologies, innovative practices and policy. The proficiency of the value chain means little if the supply from aquatic ecosystems collapses. As our research revealed, in Burkina Faso value chains are heterogeneous in terms of number of links and diversity socio-professional characteristics of the actors, one reason being that almost anyone can become a fisherman. Access is easy because no special skills or special equipment are required, and a good financial return is gained by most entrants. While regulations exist on paper to control equipment use, there is no consistent, effective enforcement of those regulations. Fishermen gain the highest profit margins, e.g. (82% to 93%) vs. Fishmongers (4% to 19%) and Processors (9% to 19%) in the value chain. However, while the fishmongers receive a smaller profit margin than fishermen, through their total throughput they earn over-all much more income than fishermen. On this basis, women often are providing loans and other financial support to fishermen, allowing them to purchase equipment. However, the impact of pre-financing on competition between fish processors and fishmongers should be researched further. It seems that expensive investments in transport can cut into the higher gross income of fishmongers, and, if there is pre-financing by the fish processors, then significant returns go to them first.

Access to fish without the need to invest much for skills or equipment (generally gained by loans from women) means that most fisherman are generalists who catch any and all species they can. As with skills, such fishermen do not invest in learning about any species of fish, its needs, the present condition of the population or of the environment. As a result, the current attractiveness of fishing can lead to overfishing in a field increasingly crowded with fishermen ignorant of the conditions that sustain aquatic ecosystems. Overfishing leading to declining returns is inevitable. This potential for saturation leading to overfishing is a mandate for ecosystem-based fishery management. Without ecological stability, the industry will collapse under a wave of inexperienced fishermen. This section assesses the challenge to sustain ecosystem quality while modernizing the value chain into a well-structured system of actors with skills and knowledge based on certain species. Without such knowledge, cooperation between fishermen and the government is impossible, and governance must rely entirely on coercive enforcement. The following section frames the question of how enforcement can become effective in controlling over-fishing by considering the possible combinations of agencies and actors might employ different tools of enforcement.

Barriers to Restoring Natural Fish Populations as a Resilient Foundation for the Value Chain

Overfishing is not the result of any single cause. It emerges from many factors which are linked in multiple patterns of behavior. This section explores some hypotheses about what some of those patterns are and how they are linked. Such policy challenges are quite complex, but this work represents a start at establishing what are some of the fundamental causes of the overfishing problem.

As previously established, fishermen realize the highest profit rates in the fish value chain. This attracts men from all sectors of rural society to try fishing for part of the year. While competition and relatively low yields force most to rely on other sources of income, fishing continues to attract very high participation rates. Figure 49 shows how *Profitability* can drive a feedback that reinforces increases in the number of fishermen, and hence *Fishing Rates* and *Harvest Income*, which feeds back to increase profits. Unchecked, this reinforcing feedback loop will continue to drive all values higher and higher. One should note that this figure models the current dilemma but does not address the potential for fishing rates to drive excessive harvests and cause production to plateau or collapse, thereby destroying the base of the fishing value chain.

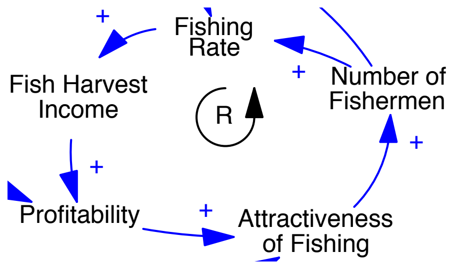


Figure 49: Profitability driving high fishing rates

Such a reinforcing feedback loop increases the number of fishermen and sustains fishing rates too high to permit fish populations to restore their natural reproductive capacity (see Figure 45). Proper *Enforcement* might police aquatic areas to control *when* fishing occurs, limiting the *Fishing Rate* as well as *how* fishing occurs, controlling the kind of equipment (“kit”) used and the manner of its use. It can also control *if* fishing occurs by granting licenses to a select number of applicants, checking whether their knowledge and skill level qualifies them to fish. Such enforcement would further constrain fishing by raising the *Cost of* Entry to the fishing profession, thereby lowering the profitability, and hence the attractiveness of fishing. Figure 50 summarizes these controls as a set of balancing feedback loops that constrain the driving force of the Reinforcing feedback loop.

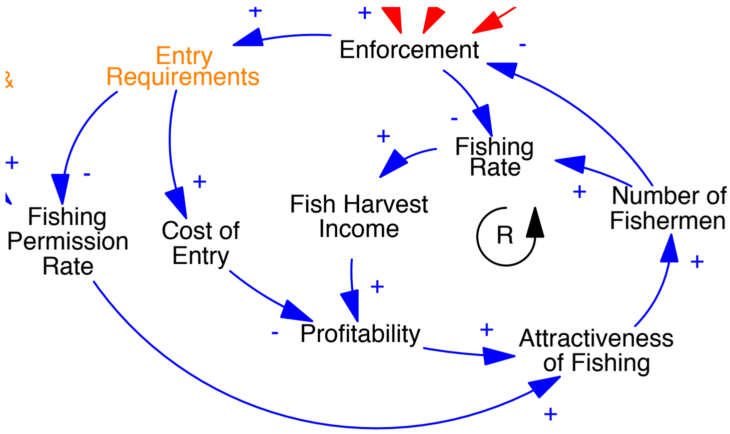


Figure 50: Enforcement as a check on high fishing rates

In many traditional cultures around the world, various species have human "protectors" or "stewards", who are responsible to know the conditions of prey populations of that species and use that knowledge to control access to those resources and thereby maintain their integrity. Figure 51 expands the diagram to include four potential actors (identified by a brown, bold font). These actors might contribute to that "protector" function either individually or in coordination with each other. Enforcement can be administered by agents of the *Traditional Government* (*Kotigi* or *Tengsoba*), by officers and/or members of *Fishermens Associations,* and by agents of the *National Government* or their regional proxies. One example of the latter might the so-called *Extension Services*, which function in many nations as experts to train farmers, fishermen and other uses of natural resources in the skills needed to sustainable use those resources. Such agents are almost wholly lacking for fisheries in Burkina Faso. The factors (kit, skills, knowledge, and entry requirements) by which enforcement agents might enable or deny access to fishing are shown in orange font.

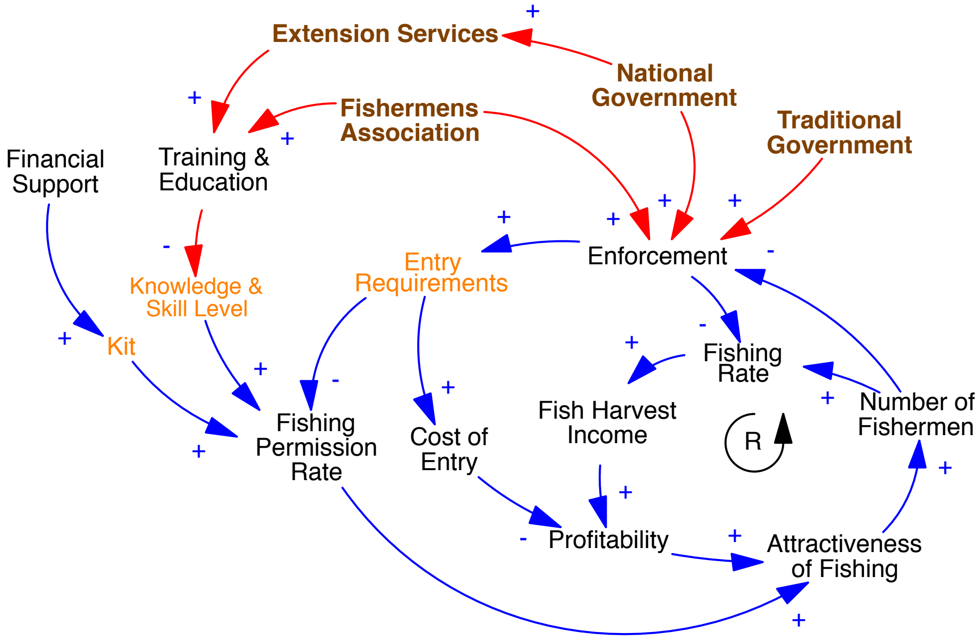


Figure 51: Governance failures leading to overfishing

Gender - Barriers to the Second Phase of the Demographic

Fishing has emerged relatively recently (1950) as a major economic activity in Burkina Faso. However, the contributions of men and women have not followed "modern" industrial patterns from the Global North. They have been shaped by traditional notions of gender roles. Men exclusively catch fish, and women enhance production through post-harvest activities. These include processing, maintenance, marketing, and repair of fishing gear and equipment.

Such gender role differentiation is rooted in traditional patterns of family organization (patrilineal and patrilocal). Women's main roles have been familial and social, i.e. taking care of the immediate needs of the family. Women are a significant economic force in Burkinabe society, sometimes providing the entire income for a household. They spend most of their income to contribute to household welfare by improving nutrition and health. It is perhaps the channeling of women's activities to sustain households that makes them reluctant to try relatively new skills of fishing. In a world centered on domestic responsibilities, they have no precedent or starting point to go far afield into what is clearly demarcated as male territory – the providers who roam far and wide.

Women in Burkina Faso are a major force within their household and the domestic arena, but they have a widespread network for their businesses that they run outside the household, which provides working possibilities for family members. Women in Burkina Faso traditionally do work outside the home in the marketplace. As traders, women have developed sophisticated capacities to deal with fluctuating offers and demands as they hedge against uncertainty by diversifying in selling many, different things and investing in new ways to earn money. As traders whose purchases supply the markets, women are a major driver of what natural resources are drawn into market channels.

This extension of women's domain beyond the household is supported both by grandparents as well as children taking up domestic duties. The entire household, much wider than family, takes up such duties, even more distant relatives or a friend of the family who has come to town, looking for work, can be integrated into the household work sphere. As in the marketplace, women play a pivotal role in connecting production with the consumer. It is this capacity that has the potential to help drive development of aquaculture and natural capture fisheries. In the latter case, they (usually women) often develop business relations with fishermen by funding and otherwise supporting them (equipment repair). Fishmongers are mostly married women who often send unmarried women as agents to purchase things. As such, the married women are the key directors of all the purchasing opportunities and choices that pull fish into the value chain. They significantly influence the amount and quality of the fish harvest in the sense of which species, which size and which amount. Fishmongers are economically the most important actors (compared to fishermen) in the fish sector. These business initiatives bind a fisherman to a woman, guaranteeing her a supply of fish to process. Women organize into groups to increase leverage and access to funding, training and supervision that can enhance their capabilities, both individually and as a group. As traders, they have a personal interest in augmenting the quality of the fish harvest. Through their trading choices, they play a key role in the vicious circles of low-price fish imports. They deal with volatility of commodity prices at first-hand.

It is clear that the fishing industry has emerged along traditional lines of gender, but in these early days there still appears to be some room for flexibility and innovation. The very rapid shift from riverine to reservoir fishing over only a few decades required swift development of fishing skills and institutions from scratch. It remains possible that tradtional gender roles have not been firmly institutionalized into a common set of skills and knowledge that are part of the accepted structure of society. We are in a novel transition where novel arrangements and compromises between republican and traditional ways are repeatedly tested, but not in a way that adds up to a sustainable path to the future.

Barriers to Women Assuming Wider Roles in Fisheries

The actual catching of fish in the fish capture industry is predominantly done by men, but such dominance may not be the salient gender issue in Burkinabe fisheries. Women provide most of the backbone as well as the brains that guide the processing and sales of fish for all sectors, e.g. capture, imports and aquaculture. Almost all fishmongers and processors are women, and as such they make the decisions about purchases from each of these sectors. Figure 52 shows women's impact as the ways that *Fish Market* Sales reflect changes in purchase decisions by *Fishmongers and Processors Influence* that change or drive *Import Rate, Harvest Purchases, Production Purchases*.

Purchase decisions are currently driven by availability and price, so cheaper foreign fish imports dominate the markets, especially the urban ones. But these decisions also depend on the quality of fish available, so women have an inherent interest in clean fish that come from unpolluted environments. Their purchase decisions to avoid unclean fish influence the market but have only an indirect influence on the causes of pollution and low fish quality, e.g. pollution from urban effluents and rural land uses and runoff, deterioration of habitat quality and ambient water quality (see Section 3 for a detailed list). Improving and sustainably managing these environmental issues requires better initiative and oversight, e.g. *Sustainable Fisheries Governance*, to improve *Enforcement* (see Figure 50) to eventually bolster *Habitat and Aquatic Ecosystem Integrity*. These could lead to improvements both for the capture fish industry as well as aquaculture production.

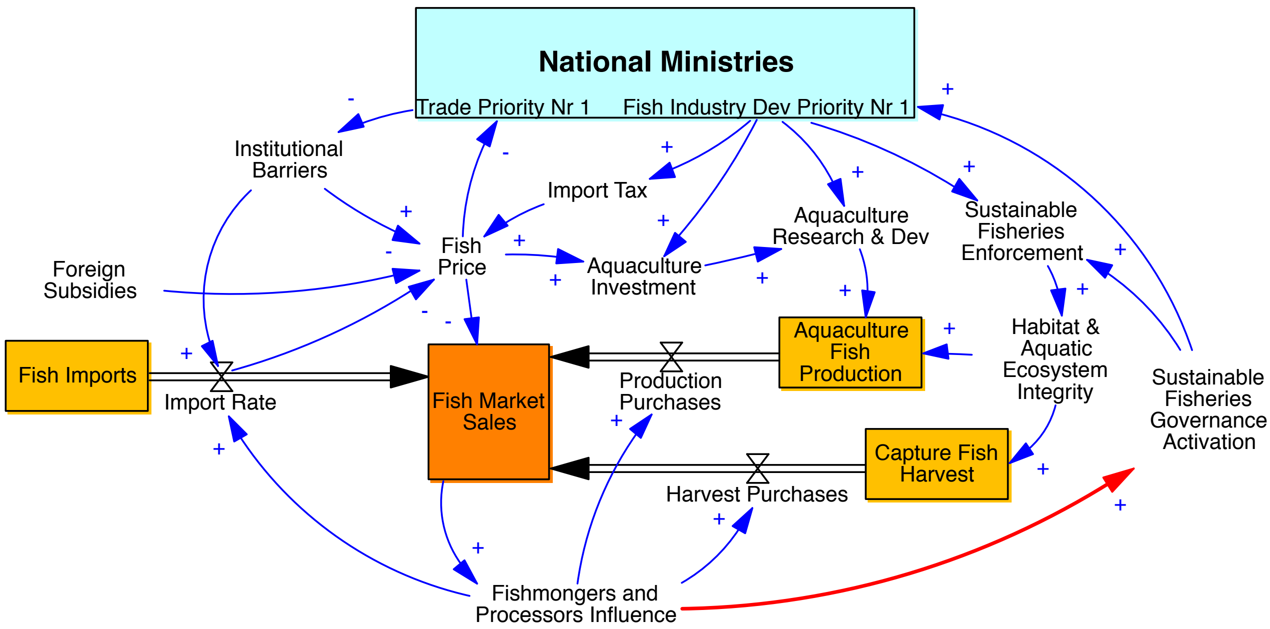


Figure 52: Women's influence as traders and processors on fish production and trade in Burkina Faso

A key challenge is that fishing governance in Burkina Faso has never sustained programs of education, enforcement of policy or research and development that establish common understanding of the issues or trust in governance. As reported in Section 8.1, institutional nomadism has shifted responsibility for fisheries governance so often that there is no agreement on who is in charge and how to proceed. Amidst such uncertainty, there is no understanding or consequences to prevent resource use at maximum levels.

One factor contributing to this confusion is the lack of influence of people with real economic interest in fisheries. Women as traders and processors (either individually or as associations) have only marginal influence on the effectiveness of *Sustainable Fisheries Governance* (red arrow). Their interest in cleaner fish and a cleaner environment is scarcely realized in the formulation and implementation of fishery policies. The direction and effectiveness of governance might shift if women's market experience and preferences could be added to the inputs to local, regional and national governance, and their influence might grow as their experience and skills in governance grow. For example, to fill the production shortfall of Burkinabe fish capture and production, national government policy favors short-term solutions like boosting imports over longer-term strategies to improve and modernize the fish capture and aquaculture sectors. Women's interest, both in a cleaner environment and domestic stability, might help shift government priorities from trade to longer-term investments to increase and improve their fish supply chains by research and development in aquaculture as well as improving the quality and quantity of capture fish production. This might be the basis for testing policies that have worked in neighboring Ghana to limit fish imports so as to create the space to develop their aquaculture industry.

Synthesis

Sustainability science is founded on the premise that policy failures of the past century resulted from a flawed assumption, which trapped them from the outset: that one discipline (usually economics or engineering) was sufficient to frame the issues and research potential solutions. This project avoided that trap by expanding the scope of inquiry to include natural sciences, agro-engineering, economics, and social sciences. Each discipline or set of disciplines raised separate questions that, by themselves, identify patterns of behavior that can significantly reduce the chances of achieving food security through the establishment of sustainable fisheries, be they natural or artificial. The relationships that link these four areas offer insights into the ways that different sectors of nature and society reinforce the behavioral patterns that imprison fisheries in a degraded state, increasingly incapable of supporting food security.

Following this multidisciplinary approach we examined four issues of current interest to the sustainability of fisheries in Burkina Faso: the regeneration trap in ecosystem restoration, the barriers to aquaculture development, the challenge of governing the foundation of the Fishery Value Chain, and finally the issue of gender, especially women's potential roles in making fisheries more sustainable and thereby gaining better food security. Figure 53 summarizes the relationships linking these four issues as part of improving food security in Burkina Faso. For clarity each pathway or relationship is labeled with a letter in red font, and then described in more detail in the text below.

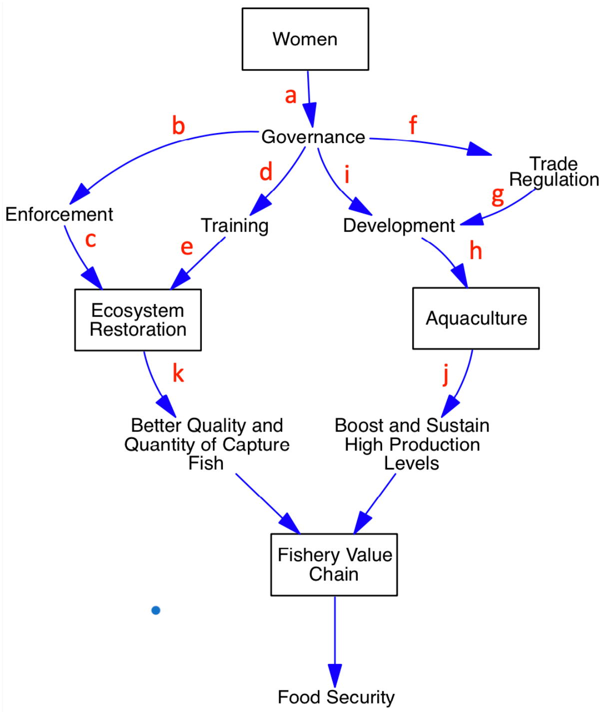


Figure 53: Synthesis

Beginning from the top, women can bring the experience of the marketplace (a) to bear in balancing economics with politics in governance. This might help their objectives of guaranteeing the supply (j and k) of quality fish (k) through ecosystem restoration by enhancing enforcement (b) of fishing policies or of land use and pollution control. These objectives could also be achieved by developing training (d) to improve the knowledge and skills of fishermen, thereby better protecting habitat as well as fishing with the limits of the existing fish populations. Improved governance might also try regulating trade (f) such that the subsidized, artificially low price of imported fish does not stifle investment (g), and hence development (h) of aquaculture. Governance could also directly target research and development (i) to establish a modern, functioning aquaculture industry.

Points of Intervention

A) Regeneration Trap

- Local aquatic ecosystems and their fisheries should be experimentally restored on a case-by-case basis. Pilot studies should test various approaches to increase local food supply and security and thereby lower fish demand long enough to restore the integrity of local habitats and the productivity of fish populations.

B) Aquaculture

- Assign a clear responsibility to a ministry to develop aquaculture through funded research involving pilot projects and programs to train private sector civilians in the skills (business, scientific, production) and sustain this arrangement for long enough (minimum five years) to establish trust and understanding across society and increases compliance and cooperation with fisheries policy.

C) Value Chain

- The foundation of the value chain for capture fisheries should be strengthened by better enforcement to raise the standards of knowledge and equipment employed by those permitted to fish and to control the absolute number of fishermen who can access the resource.
- Knowledge and skills need to be enhanced by establishing and running an Extension Service exclusively for fisheries to provide better quality training for fishermen.

D) Gender

- Women as traders should be integrated into fisheries governance as their choices will support development of the elements of national fisheries production, e.g. natural fish capture and aquaculture. This can be accomplished by incorporating women's trade associations into governance institutions.
- Training programs for women should be expanded beyond the normal focus of domestic issues and be designed to enhance their economic and management capabilities.

12. Visions for the Future

Raymond Ouédraogo and Nomwine Da

The SUSFISH project targeted the three main components of the fishery in Burkina Faso, namely the political, human and natural components whose interactions results in the production of the fishery. Reliable results have been obtained and must be used. To this end, the general objective of these recommendations is to promote the integration of results into the formulation and implementation of fisheries and related policies. To achieve this, for each recommendation the relevance of the subject will be explained before making the recommendation itself.

Protection of Fish Migration

Fish migration is of crucial importance in fish ecology, especially fish reproduction. More generally, the protection of the longitudinal connectivity of watercourses is prescribed by legislation, in particular by the Law on the Orientation of Water Management in Burkina Faso (AN, 2001), Article 40 of which states: "Works built in the bed of watercourses must maintain a minimum flow guaranteeing aquatic life. When they are located in watercourses frequented by migratory fish, they must also be equipped with crossing devices" (own translation). However, the subject has not been studied much in Burkina Faso. As a result, no prototype fish ladders or reliable fishways are available. It has been shown that any watercourse, no matter how small, is a fish migration route. This allows colonization of new reservoirs and, annually, seasonal water bodies (Arrington *et al.,* 2005; Kerezsy *et al.,* 2017).

Recommendation: Article 40 could be reworded to state that any dam (dike) must have a fishway regardless of the type of watercourse on which it is built. Legislative texts should also be popularized, attempts should be made to incorporate crossing structures and research in this area should be encouraged.

Sampling of Fish

In Burkina Faso the fisheries administration and the research services often undergo fish sampling also called experimental fishing. However, the sampling strategy differs according to the institutions, the persons involved, the means used, etc., making it difficult to compare the fish population from one water to another or to study its temporal evolution in the same water. This problem was encountered when drawing up the red list of fish species, which consisted in assessing the conservation status of fish species; this required a historical trace of the frequency of species in the national territory. The disparity lies in the fishing gear used, the season, the expertise of the personnel (fishermen and scientists), the choice of habitats, because the diversity of the species caught depends on it.

Experimental fisheries can then be standardized. To this end, a technical note was prepared and accepted by the National Center for Scientific and Technological Research in 2017. It stipulates that to fish as many species as possible, sampling will be carried out in the rainy season, the cast net will be used, and fishing will be carried out in the greatest diversity of habitats. In addition, other fishing gears will be used and commercial fishing catches will be observed. This technical note should be applied after improvement if necessary.

Governmental Aquaculture Farms

During the study on aquaculture potentials and the study on enhanced fisheries, it was realized that the state's aquaculture stations are facing enormous technical difficulties that do not allow them to fully achieve their objectives of being sites for research & development, training and demonstration of technologies in the field of aquaculture as well as ensuring the availability of fish seeds (Ouédraogo, 2016; Da *et al.*, 2019; Sawadogo *et al.*, 2019). Thus, in some stations a good number of ponds cannot be supplied with water by gravity (Figure 54) as initially planned. In other stations, ponds are regularly flooded, and finally the construction of ponds in other stations has begun but has never been completed.

<u>Recommendation:</u> A technical audit should be carried out on those state farms with technical problems. The history of the farms or their extension will be made, emphasizing the defects noted in the feasibility studies, the qualifications of the

personnel involved in the construction of the infrastructure, the technical-administrative procedures, and possibilities for correction will be proposed.

Figure 54: Bazèga Aquaculture Station: Ponds unable to be filled with water by gravity (Source: R. Ouédraogo)

Private Aquaculture Farms

The study on aquaculture potential found that the monitoring of private farms by the fisheries administration focused only on the technical, e.g. bio-chemical and physical, aspects of aquaculture, with little attention to the economic aspects that are sometimes completely ignored. However, aquaculture activities can only be sustainable if they are economically viable. In other words, reasonably speaking, no one will invest in aquaculture if it does not generate income. While there are more and more candidates for aquaculture, the promotion of privately led aquaculture is one of the priorities of the current national fish resouces strategy. But the private sector will not support it until its financial profitability is proven.

Recommendation: When setting up private aquaculture farms, technicians must analyse the potential for financial profitability, despite the absence of an economist or socio-economist in fisheries administration. Provision of such expertise will help reveal the socio-economic aspects of aquaculture in particular and also fisheries in general.

Enhanced Fisheries

The expansion of the production potential of fisheries is one of the priority actions of the national fisheries strategy (MAHRH, 2010), which is also encouraged by the Forest Code (AN, 2011). In Burkina Faso, the most important amplification actions are restocking of fish, the introduction of species and the development of spawning grounds. As illustrated in Figure 56, for the past two decades, restocking campaigns have been organized annually, with juvenile fishes coming mainly from state aquaculture stations (Da *et al*., 2019). Introductions of new species are also underway, but few cases are reported. We were not aware of any successful and properly documented introduction, but failures were reported. This is the case of *Heterotis niloticus* in the Boulmiougou reservoir in Ouagadougou in February 1986 (Baijot *et al*., 1994) and Boalin/Ziniaré in 2005 (Ouédraogo *et al.,* 2015). Spawning ground management consists of delimiting a flooded area and ensuring that fish use it for breeding purposes. The fisheries of Ziga, Kompienga and Bagré benefited (Figure 55). The Kompienga and Bagré reservoirs are subject to seasonal fishing closures. Unfortunately, this restricted access is still being rejected by some fishermen and female fish processors who declare that they have no alternative source of income if fishing is banned. It should be noted that neither fish stocking, nor spawning ground management, nor species introductions, nor seasonal closure of the fishery benefit from an adequately developed strategy, including an appropriate monitoring plan to ensure proper documentation of the activity. In other words, there are no standards for spawning ground management (identification, sizing and delimitation), restocking (species, storage density, species present in the water body, etc.), species introduction and closure of fishing.

Recommendation: Technical frameworks (guidelines or standards) should be developed and applied for each of the most common types of amplification. This work will be based on the literature but also on the experiences of fisheries administration in Burkina Faso and neighbouring countries.

Figure 56: Packets of juvenile fishes at the launch of the 2018 restocking Campaigns at the Samandeni reservoir (Source: lefaso.net.)

Figure 55: Kompienga reservoir - a bound of the spawning area (l) and a notice indicating the spawning ground (r). (Source: Batiéné M. (2016))

The List of Fish Species

Burkina Faso does not yet have an official list of fish species existing in the country. However, it is a legislative requirement enshrined in the Forest Code (Assemblée Nationale, 2011) which, in its article 177, states that:

> *A ministerial decree shall list the fish species already existing in the Burkinabe waters and whose handling and transfer from one region to another within the country does not require any prior authorization*.

Even without this request, it is scientifically and technically reasonable to have a list of Burkina Faso's fish species. Through fish sampling over a very large part of the country, SUSFISH has identified 83 fish species. However, crucial areas could not be visited due to political insecurity. This is the case for the protected areas in the eastern part of the country, which probably hosts species not found elsewhere. Therefore, at the moment the list of fish species is not handed over to the fisheries administration for the next administrative steps of formalisation.

Recommendation: After the SUSFISH project, the fisheries administration should continue the exploration with the technical support of INERA and/or the Laboratory of Animal Biology and Ecology of the University Joseph Ki-Zerbo. To do this, it should be remembered that good planning is necessary to achieve the objectives set (Ouédraogo *et al.*, 2015). Even if during the rainy season, the roads are not very practicable, and it is during this season that most fish species are found (Ouédraogo, 2010 and Mano, 2016).

Overview of the Future Project

As in SUSFISH, the activities of a future research and development project will be based on the problems experienced in the contribution of fisheries to socio-economic development. Thus, siltation of water bodies is a major concern to the point that the rehabilitation of a natural lake is being implemented and that of another lake is being formulated (Ouédraogo R., 2018 and APPEAR, 2020). Some of the phenomena that may attract the project's attention are the interaction between domestic animals and water bodies, particularly fish production.

The interaction between domestic animals and fish extends into aquaculture, whose production and integration into agro-sylvo-pastoral activities is strongly encouraged in Burkina Faso. The project could therefore focus on fish farming integrated with rice, poultry and pig farming. This form of aquaculture is not intensive, but it can allow substantial production of fish and other animals while optimizing the use of natural, human and financial resources.

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Work completed within the SUSFISH projects is marked in **bold.**

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Appendix

Site Protocol .... **Site Name......................** **Date (dd/mm/yy) ....**

Habitat	1	2	3	4	5	6	7	8
Description								
Writer								
GPS-point (N/E)								
GPS-Coordinat								
Run/Throw nr.								
Start time								
End time								
Photo nr.								
Weather								
Fishing method								
Blockage								
Water type								
Fished area (m²)								
Distance bank (m)								
Secchi depth (cm)								
Condcutivity (µS/cm)								
pH								
Temperature (°C)								
O_2 (%)								
O_2 (mg)								
Probe nr.								
Landuse								
Impact								
Shading (%)								
Structure								
Dam								

CATEGORIES	1	2	3	4	5	6	7	8
Weather	sun	cloud	rain	wind				
Fishing method	1 aggregat	2 aggregat	gill net	cast net	longline	Nasse fishing	commercial	
Blockage	net	electric	barrier					
Water type	reservoir	running	con sidearm	dead sidearm	pond	Dissipation	channel	
Landuse	savanna	rice	agriculture	livestock	settlements	roads	forest	protected
	9 cotton	**10** vegetables						
Structure	tree	xylal	rock	waterplants	reed	outwashed bank		
Impact	fishing	sandmining	water abstracti	deforestation	channalisation	invasiv plant	nutrient inp	riprap
Dam	upstream	downstream	between	free flowing				

Figure 57: Habitat Assessment Field Protokol for Sub-Sahelian countries

Site Protocol ..... **Site Name.......................** **Date (dd/mm/yy) ....**

	1	2	3	4	5	6	7	8
writer								
riverbed width (m)								
riverbed height (m)								
distance to bank 1(m)								
distance to bank 2(m)								
distance to bank 3(m)								
distance to bank 4(m)								
distance to bank 5(m)								
distance to bank 6(m)								
distance to bank 7(m)								
wetted width 1 (m)								
wetted width 2 (m)								
wetted width 3 (m)								
wetted width 4 (m)								
wetted width 5 (m)								
wetted width 6 (m)								
wetted width 7 (m)								
water depth 1 (m)								
water depth 2 (m)								
water depth 3 (m)								
water depth 4 (m)								
water depth 5 (m)								
water depth 6 (m)								
water depth 7 (m)								
velocity 1 (m/s)								
velocity 2 (m/s)								
velocity 3 (m/s)								
velocity 4 (m/s)								
velocity 5 (m/s)								
velocity 6 (m/s)								
velocity 7 (m/s)								
Choriotop in %								
Pelal < 6µm								
Psammal > 6µm-2mm								
Akal >0,2-2cm								
Mikrolithal > 2-6 cm								
Mesolithal >6-20 cm								
Makrolithal > 20-40cm								
Megalithal > 40 cm								

Figure 58: continued: Habitat Assessment Field Protokol for Sub-Sahelian countries

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