


Review

# A Drivers-Pressure-State-Impact-Responses Framework to Support the Sustainability of Fish and Fisheries in Lake Tana, Ethiopia

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**Abstract:** Lake Tana, Ethiopia's largest lake, has a remarkable and conservation-worthy assemblage of fish species, requiring fisheries management for sustainable exploitation. However, due to anthropogenic impacts, many of these fish species are threatened. Hence, an improved management of these resources is recommended. To allow a more sustainable exploitation of natural resources, a better understanding of the cause-effect relationships between anthropogenic impacts and environmental components is fundamental. The Drivers-Pressure-State-Impact-Responses (DPSIR) framework is a useful tool to describe these links in a meaningful way to managers and policy makers. Despite its potential, application of DPSIR is virtually lacking in developing countries. This paper assessed the potential of the DPSIR framework and used it to comprehensively describe the available knowledge and management needs in the lake catchment. Rapid population growth and the economic transformation are the main driving forces leading to various pressures such as water quality and wetlands degradation as well as declining fish community, which is detrimental to the socio-economic state and health of the local inhabitants. As feedback to the driving forces, pressures, state changes and impacts, optimal multi-level responses are developed. This study aims at providing policy makers a better understanding of the lake catchment in order to bridge the gap between science and decision-making.

**Keywords:** endemic fish; fisheries management; human pressures; state changes; responses

## 1. Introduction

Ethiopia has more than 24 natural lakes and many artificial reservoirs, with a total surface area of about 7500 km<sup>2</sup>. The major rivers stretch over 7000 km. Based on the composition of their fish fauna, Ethiopian freshwater systems are classified into seven drainage basins: Abay (Blue Nile), Awash, Baro-Akobo, Omo-Gibe, Rift Valley Lakes, Tekeze and Wabi-Shebele Genale [1]. Lake Tana, the country's largest lake, contains four main fish families: *Namacheilidae*, *Cichlidae*, *Clariidae* and *Cyprinidae* [1,2]. The first three families are represented by a single species; *Afromacheilus abyssinicus*, *Oreochromis niloticus*, and *Clarias gariepinus*, respectively. *Cyprinidae* is the most abundant family, which consists of three genera and 24 species. The three genera are: *Enteromius* (three species) [3], *Garra* (four species) [4] and *Labeobarbus* (17 species) [5,6]. Of the 27 fish species in the lake, 21 are endemic [1] and 17 (76%) of the endemic species belong to the genus *Labeobarbus*. The wide range of different habitats in the geologically young lake [7], in combination with the 40 m high Tissisat

("smoking water") falls that completely isolates the lake's ichthyofauna from the lower reaches of the Blue Nile River are most likely the main reasons for its high endemism. The lake and adjacent wetlands have a high biological, ecological and socioeconomic value, since they provide various goods and services to more than 500,000 people [8].

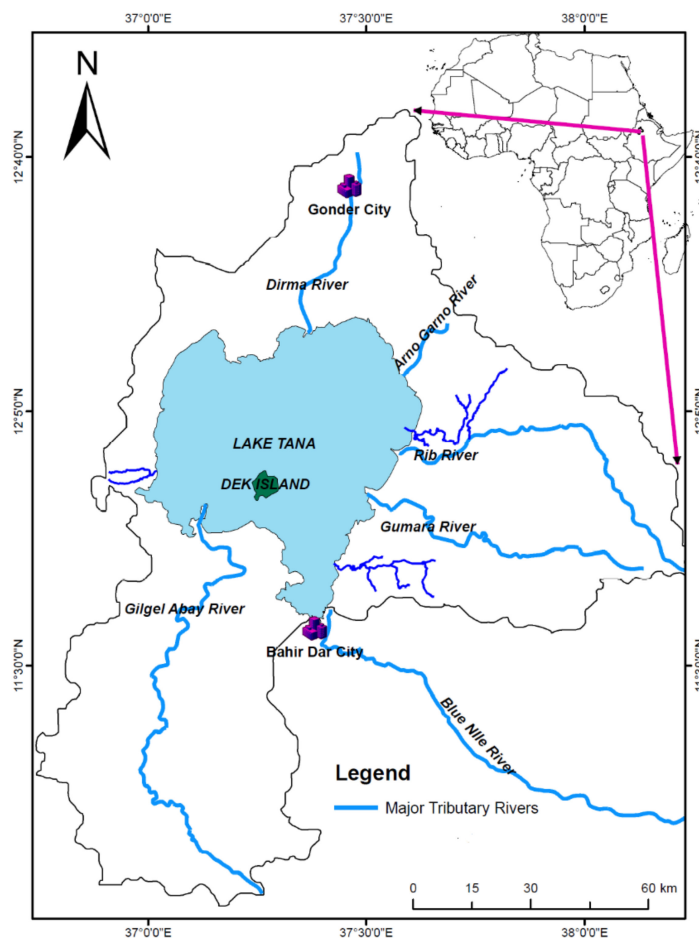
Nevertheless, relatively recent, anthropogenic activities have put the Lake Tana fish and the attributes of the fisheries at risk. Many researchers are concerned regarding the detrimental anthropogenic effects on the local lake fisheries [1,9–11]. The major pressures on the fish and fisheries in Lake Tana are: (1) illegal fishing, (2) damming and urbanization leading to habitat and/or breeding ground degradation, (3) waste discharge, (4) sand mining, (5) lack of institutional nexus and fisheries management [1,10–15].

Recently, concerns regarding the fisheries in Lake Tana have intensified the discussion between the different sectors. Thus, to support fishery managers and policy makers, sound scientific results need to be integrated into a framework that identifies key pressures and optimal solutions. Conceptual frameworks are required to understand, summarize and visualize the actual situation in a manner familiar to managers and policy makers [16,17]. Among the several conceptual frameworks for describing the links between human pressures and state-changes in aquatic systems, the Drivers-Pressure-State-Impact-Responses (DPSIR) framework has been widely used [18]. DPSIR was adopted as a conceptual framework by the European Environmental Agency in 1995 [19] and proposed by the Organization of Economic Co-operation and Development [20] as a means of structuring and organizing the cause-effects relationships between human activities and environmental components in a way that is meaningful to managers and policy makers. In particular, it is an approach, which is recommended to study fisheries [21].

Despite its wide use in Europe, DPSIR is not well known in developing countries like Ethiopia [22]. The links between human pressures and environmental components in the Lake Tana catchment are not well documented. Nevertheless, the recently established Ministry of Agriculture and Livestock Resources has taken the responsibility to overcome conservation challenges of fish communities and the related fisheries in Lake Tana. This calls for a better understanding on the causal dependencies between a broad set of human activities and their various effects on the lake ecosystem. A better understanding of the interactions between the drivers, pressures, state changes and impacts is important to come to valid responses. To this end, this paper provides comprehensive understanding of the lake's fish resources and conservation problems valuable for both local fishing authorities and international readers.

## 2. Methods

Lake Tana, the source of the Blue Nile River, originated some two million years ago as a result of a volcanic blocking of the Blue Nile River [23]. It is situated on the basaltic plateau of the northwestern Ethiopian highlands at 12° N, 37°15' E at an altitude of approximately 1800 m (Figure 1). The shallow lake, with an average 8 m and maximum 14 m of depth, contains half of the country's surface freshwater. The lake has a surface of approximately 3050 km<sup>2</sup> and has more than 60 perennial and intermittent tributaries. The lake has a watershed covering approximately 11,650 km<sup>2</sup>. The 40 m high waterfalls isolate the lake from the lower reaches of the Blue Nile River at Tississat ("smoking water"). The temperature of Lake Tana ranges from 20 to 27 °C. Despite the continuing deterioration of the water quality due to a lack of wastewater treatment, the lake still serves as a water supply for both drinking and washing. The potential of the lake and its catchment for irrigation, hydroelectric power, water supply, high value crops, livestock, fish production and eco-tourism makes it a developmental corridor for the national economy [24]. Considering its national and international importance the lake was registered as a UNESCO biosphere reserve in 2015.



**Figure 1.** Map showing the Lake Tana catchment and its major tributaries.

We reviewed various sources of DPSIR-related literature [18,21,22,25–28] to define the following five elements of the framework: (1) driving forces are identified as general human needs responsible for pressures on the ecosystem, (2) pressures are the actual human activities that affect the lake ecosystem, (3) state changes describe the condition of the lake ecosystem components affected by pressures, (4) impacts are human health risks or socio-economic losses, and (5) responses are the feedback to driving forces, pressures, state changes and impacts. A first step consists of identifying the major driving forces, pressures, state changes and impacts in the lake catchment. To identify the first four elements of the framework, we reviewed the currently present scientific literature on the biology, ecology, and major challenges of the fish communities and fisheries in Lake Tana. The responses were described based on this review in combination with personal experience, informal communication with local inhabitants particularly fishers and by consultation with experienced fisheries experts and scientists. Finally, we adopted the DPSIR framework to understand, summarize and visualize the actual situation of the Lake Tana catchment and to propose optimal management options. To this end we provided a description of the current biological aspects of the local fish and the socio-economic interactions in Lake Tana. In a final section we integrated this knowledge in the DSPIR framework for the Lake Tana area.

### 3. Description of the Current Biological, Social and Economic Actors in Lake Tana Area

#### 3.1. Fish Species in Lake Tana

Distribution and abundance of fish depends on the quality of their habitat and spawning grounds. However, in Lake Tana, the physical, chemical and biological characteristics of these areas are severely

affected by different anthropogenic activities. The lakeshore areas and the tributary rivers and streams are highly vulnerable to these impacts. For instance, damming and sand mining are detrimental to spawning grounds of the migratory endemic *Labeobarbus* species in Lake Tana [11,15]. Moreover, flood recession agriculture is negatively affecting the habitat and nursery sites of many fish species in the lake [10]. Therefore, degradation of these areas could have a large impact on the survival of the fish species in the lake (Table 1) [29,30]. In this section we briefly describe the reproductive strategy, habitat preference and feeding habit of the fish in the lake. A detailed explanation of the links between anthropogenic activities and ecosystem functions are presented using the DPSIR framework in the next sections.

Lake Tana fish species have different reproductive strategies, whereby some species breed in the shore areas and lake-associated wetlands, while others migrate to the floodplains or upstream river [9,13,31–33] (Table 1). Nine *Labeobarbus* species migrate in search of ideal breeding grounds with high gravel beds, and clean and oxygen-rich waters. *Clarias gariepinus* migrates to the floodplains for spawning. Chemo-physical gradients may guide the migratory fishes to aggregate at the river mouths [9]. Flooding events, which increase the lake water level and turbidity, are also likely to trigger their migration [13,32]. The non-migratory *Labeobarbus* species are thought to have adopted a new reproductive strategy [13] and may breed in the lake itself or lake associated wetlands.

With exception of *L. osseensis*, which was only reported in the Bahir Dar Gulf, the remaining species are found all over the lake. However, their habitat preferences vary; some predominantly prefer rocky substrates, while others prefer muddy or sandy substrates. Some fish species live in areas with water depths of less than 6 m, while others mainly live in areas with depths greater than 6 m (Table 1) [5].

*Oreochromis niloticus* primarily feeds on phytoplankton, whereas *Enteromius* and *Garra* species feed on zooplankton and *C. gariepinus* is omnivorous (Table 1). Despite the lack of teeth in their jaws, eight *Labeobarbus* species in the lake are piscivores, while the rest feed on plankton, macrophytes or detritus [31].

**Table 1.** Aspects of habitat and feed preference, reproductive behavior, spawning grounds and IUCN status of Lake Tana fishes (shore areas also include lake associated wetlands. Streams with high gravel beds, clean and high oxygen water. “-” refers to no data available.)

Species	Preferable Habitat (Water Depth)	Feeding Strategy	Reproductive Strategy	Spawning Grounds	IUCN Status since 2000
<i>A. abyssinicus</i>	Shore areas	Phytoplanktivore	Lacustrine	Shore area	Not evaluated
<i>B. humilis</i>	Sub-littoral (intermediate)	Zooplanktivore	Lacustrine	Shore area	Not evaluated
<i>B. tanapelagiis</i>	Offshore (>6 m)	Zooplanktivore	Lacustrine	Shore area	Least concern
<i>B. pleurogramma</i>	Shore areas (wetlands)	Benthivore	Lacustrine	Shore area	Not evaluated
<i>C. gariepinus</i>	Shore areas and sublittoral	Omnivore	Lacustrine	Flood plain	Least concern
<i>G. dembecha</i>	Benthic	Phytoplanktivore	Lacustrine	Shore area	Least concern
<i>G. dembeensis</i>	Benthic	Phytoplanktivore		Shore area	Not evaluated
<i>G. regressus</i>	Benthic	Phytoplanktivore	Lacustrine	Shore area	Vulnerable
<i>G. tana</i>	Benthic	Phytoplanktivore	Lacustrine	Shore area	Vulnerable
<i>L. acutirostris</i>	Muddy and sandy substrate (>6 m)	Piscivore	Migratory	Stream	Vulnerable
<i>L. beso</i>		Phytoplanktivore	Lacustrine	Shore area	Least concern
<i>L. brevicephalus</i>	Muddy, sandy and rocky substrates (<6 m)	Zooplankton	Migratory	Stream	Not evaluated
<i>L. crassibarbis</i>	Offshore (>6 m)	Benthivore	Migratory	Stream	Not evaluated
<i>L. dainellii</i>	Rocky substrate (>6 m)	Piscivorous	Lacustrine	Unknown	Not evaluated
<i>L. gorgorensis</i>	Muddy, sandy and rocky substrates (<6 m)	Molluscivore	Migratory	Stream	Not evaluated
<i>L. gorguari</i>	Rocky substrate (<6 m)	Piscivore	Lacustrine	Unknown	Vulnerable
<i>L. intermedius</i>	-	-	Migratory	Stream	Not evaluated
<i>L. longissimus</i>	Rocky substrates (<6 m)	Piscivore	Lacustrine	Unknown	Not evaluated
<i>L. macrophthalmus</i>	Muddy, sandy and rocky substrates (>3 m)	Piscivore	Migratory	Stream	Endangered
<i>L. megastoma</i>	Muddy and sandy substrate (>6 m)	Piscivore	Migratory	Stream	Least concern
<i>L. nedgia</i>	Rocky substrate (<6 m)	Macro-benthivore	Migratory	Stream	Least concern
<i>L. osseensis</i>	Rocky substrate (<3 m)	Insectivore	Lacustrine	Unknown	Vulnerable
<i>L. platydorsus</i>	Muddy and sandy substrate (>6 m)	Piscivore	Migratory	Stream	Vulnerable
<i>L. truttiformis</i>	Rocky substrate	Piscivore	Lacustrine	Unknown	Least concern
<i>L. tsanensis</i>	Muddy and sandy substrate (>6 m)	Benthivore	Migratory	Stream	Least concern
<i>L. surkis</i>	Muddy, sandy and rocky substrates (<3 m)	Macrophytivore	Lacustrine	Unknown	Not evaluated
<i>O. niloticus</i>		Phytoplanktivore	Lacustrine	Shore area	Not evaluated

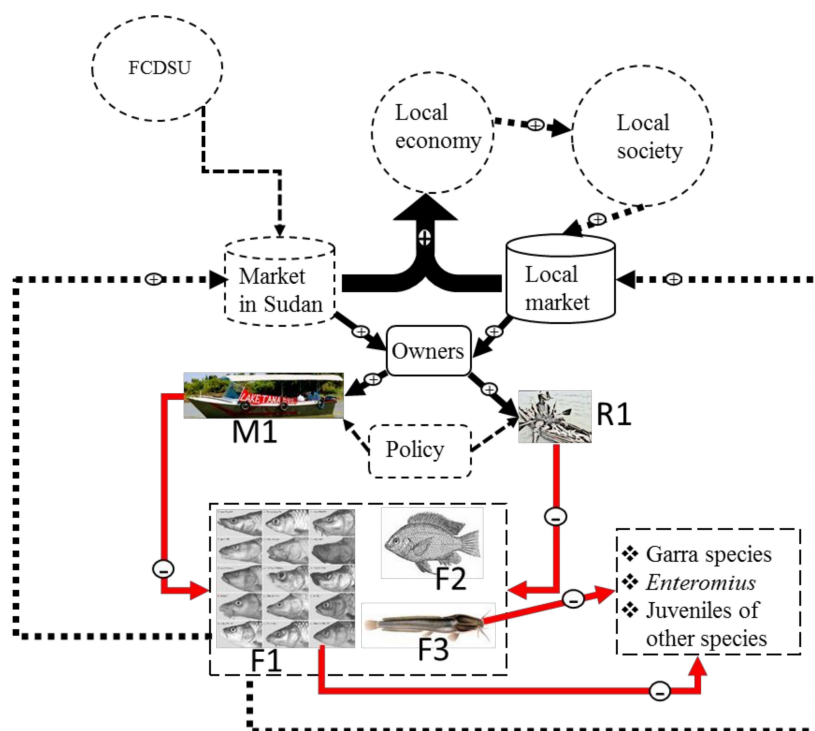
### 3.2. Socio-Economic Interactions in Lake Tana

Conservation challenges of the fish and fisheries in Lake Tana are a complex product of social, economic and ecological processes. To comprehend the complexity of the lake catchment, to manage human pressures and to optimize alternative management options, the lake fisheries and human-ecosystem interactions must be understood in their entirety. As a first step in this direction, we describe the historical fisheries development in Lake Tana and its economic importance and create a feedback diagram that shows the socio-economic interactions.

Currently, fishing is undertaken in two ways: either using single-person reed boats (a majority of the fishers) or motorized boats. The Negedie Woyto ethnic group has exploited Lake Tana fisheries since the 18th century. Until the mid-1980s, fishing activity was almost completely limited to subsistence [34]. During this period, the fishing activity was restricted to shore areas and only simple single person papyrus reed boats were used. The fishing gear were locally made traps, hook and line, and small gill nets. In 1986, two Dutch Non-Governmental Organizations together with Ethiopian Ministry of Agriculture and Orthodox Church initiated the modernization of the lake fisheries. During this time, modern multifilament gill nets and motorized boats were introduced, which were gradually being adopted by the poor members of the farming communities [34]. Nowadays, approximately 20% of the full-timer fishers own a motorized boat [35]. The mobility of the fishers who own reed boats is limited to the shore area, while those who own motorized boats have access to the open water [34]. Introduction of the motorized boat enabled fishers to access the open water fish resources and distant fishing grounds.

The lake fishery is creating job opportunities and socio-economic benefits for about 6000 fishers. Besides its direct employment and economic contribution to fishers, the Lake Tana fishery has many social values and creates job opportunities for fishery related activities. Many people are employed in fish processing, gill net making, and fish product trading (personal observations). Consequently, one can genuinely assume that a single job on the lake generates at least two fisheries related jobs on land. Local inhabitants and fisheries experts also corroborated this during informal stakeholder discussions. Thus, considering the number of fishers in the lake, the lake fisheries are creating additional job opportunities for about 12,000 people in the lake surroundings. As the average family size of the Amhara region is five, the lake fisheries are, therefore, able to support the livelihoods of about 90,000 people through the job opportunities on both the lake and the land.

Despite the increasing fish consumption demands in the neighboring country of Sudan, the majority of the catches of the commercially important species in Lake Tana mainly serve the local market. The growth, investment and mortality interactions of the lake fisheries are depicted in Figure 2. Both the local market and the market of Sudan, convert catches into investment power, which allows the local economy to grow. The local economy growth supports the society, particularly fishers, through increasing infrastructure development, market linkage and increased availability of all necessary equipment for fisheries. To increase their total catch, fishers can invest their capital in fishing efforts. Furthermore, fishers can invest in other productive assets, which in turn can further reduce vulnerability to poverty. This stimulates fishers' population growth. The fishers' population growth feeds back into the local markets and the local markets invest in fishing gears such as boats and gill nets to ensure their supply of fish. However, the increasing fishing pressure negatively affects the fish population in the lake. Due to their characteristics, the reed boat fishery has mainly impact on the inshore fish community, while motorized fishery has impact on both inshore and offshore fish communities [34].



**Figure 2.** Socio-economic interactions of the fisheries in Lake Tana. The diagram is adopted from Downing et al. [36]. Dotted arrows (associated with “+” sign) represent growth. Red arrows (associated with “-” sign) represent mortality and black arrows represent investment. FCDSU = fish consumption demand by neighboring country Sudan, F1 = *Labeobarbus* species from de Graaf et al. [37], F2 = *Oreochromis niloticus*, F3 = *Clarias gariepinus*, owners = motorized or red boat owners, M1 = motorized boat fishing effort, R1 = reed boat fishing effort.

#### 4. DPSIR Framework to Support Fish and Fisheries Management in Lake Tana

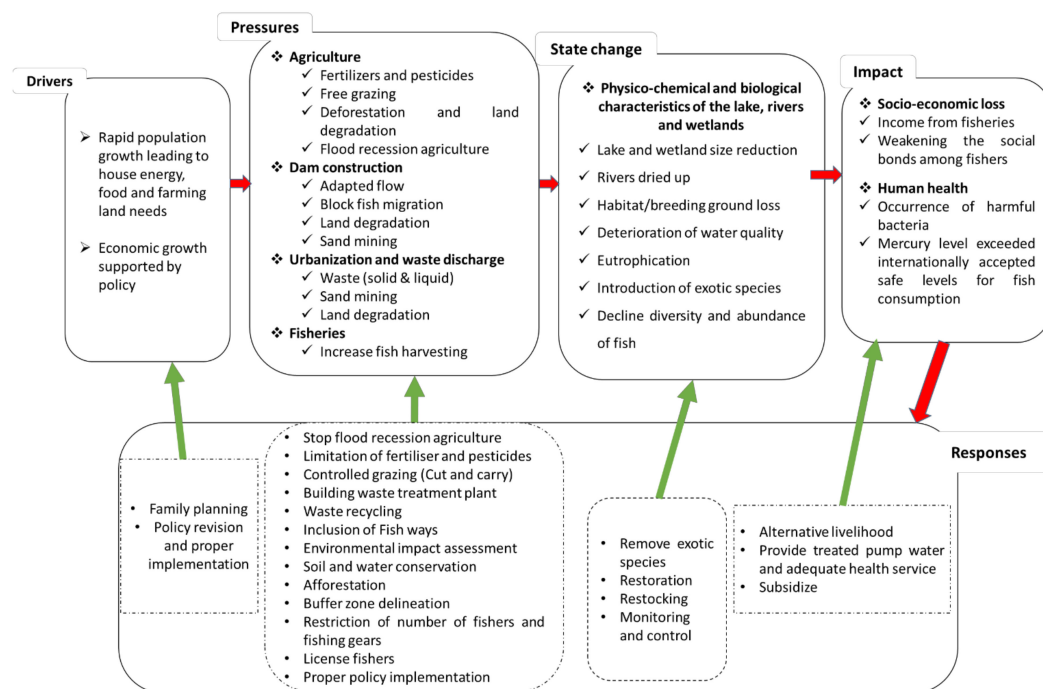
Decision making on natural resources management requires the relevant knowledge to be presented in an accessible and meaningful form. In this regard, we adopted the DPSIR framework to understand, summarize and visualize, in a simplified way, the cause-effect interactions of the lake ecosystem. Furthermore, viable response options for managing and protecting the lake resources were incorporated in the framework. In the Lake Tana catchment, driving forces exert pressures leading to state changes in the ecosystems, which then lead to impacts on humans that will in turn require a societal response (Figure 3). Different management options appropriate for the Lake Tana catchment were identified and broken-down to different levels, introduced in the DPSIR framework and connected as responses to drivers, pressures, state changes and impacts. The adopted DPSIR framework therefore provides a conceptual understanding of the interactions between anthropogenic pressures, state changes and potential management options in the lake catchment and stimulates efficient communication among policy makers, scientists and the public, improving the cooperation among them. As a result, it can potentially bridge the gap between different scientific disciplines and aid in linking science with policy and management.

##### 4.1. Driving Forces

###### 4.1.1. Population Growth

Population growth leading to increased needs of food, water and energy determines the development of natural resources in a given area. This is because the majority of the social services and development agendas designed by a government are based on this information. Ethiopia is the

second most populous country in Africa. The population growth rate in Amhara region, where Lake Tana is located, is also very high and it is the second most populous region in the country.



**Figure 3.** DPSIR framework to summarize and visualize the Lake Tana cause-effect relationships in a simplified and meaningful way. Red arrows indicate cause-effect relations from the driving forces to responses. Green arrows indicate the different suggested optimum management responses.

In the Lake Tana catchment, population growth leading to pressures such as agriculture, urbanization, waste discharge, dam construction, sand mining and fisheries, is the main driving force for natural resource degradation such as fish. About three million people (12.7% of the Amhara region population) live within the Lake Tana watershed [38]. The age group ranging from 0 to 14 years old is the most strongly represented population category, which makes the dependency ratio of the population in the lake catchment very high [39].

#### 4.1.2. National Economic Transformation

The intended economic growth supported by the current national policy is also a potential driving force to various pressures in the lake catchment. Ethiopia, has committed itself to become a low middle-income country by 2025 [40]. In order to realize its national vision, Ethiopia had set up its first Growth and Transformation Plan (GTP I) in 2010 and formulated a second Growth and Transformation Plan (GTP II) in 2016. To achieve this ambitious goal, targets have been established for several sectors including agriculture, energy and manufacture. Among others, emphasis has been given to ensuring rapid and sustainable growth through enhancing productivity of agriculture. Hence, the country intends to increase cultivable land by 13% and this policy necessitates the conversion of forestland and wetlands into cropland [41]. Besides, in order to achieve high productivity increases in agricultural output, fertilizer and pesticides use is expected to increase by approximately 100% [42]. Therefore, this could increase the amount of nutrients such as nitrogen and phosphorus in the lake, which would subsequently lead to algal blooming and invasion of weeds. Furthermore, Ethiopia has planned to increase irrigated lands by more than 400% [41] and this would stimulate dam construction in the lake catchment. Dam constructions increase pressure on habitat and spawning grounds and block the migration routes of the migratory *Labeobarbus* species [11].

## 4.2. Pressures

### 4.2.1. Agriculture

In Ethiopia, agriculture is the most important sector of the country's economy. It is the main source of livelihood for the overwhelming majority of the population. The Lake Tana catchment is highly agricultural, focusing on crop production and, to a lesser extent, livestock. The area of land used for agriculture and the amount and types of agricultural production are critical factors in determining the severity of agriculture as a pressure on the lake ecosystem. Agricultural development proponents in the lake catchment often fail to consider the biological, ecological and socio-economic values of natural resources such as wetlands. Decision makers, who are involved in natural resource conservation, are unaware of the services of wetlands ecosystems [43]. Wetland destruction and conversion to agricultural areas are still widely accepted in the national context. Driven by a lack of certified farming land, due to rapid population growth, people are forced to carry out their farming activities on hilly areas and in wetlands during the dry season. Above all, annually a campaign is organized by development agents, who are responsible for agricultural development, to dry up wetlands for the purpose of agricultural activities. Moreover, there is no policy, which limits use of fertilizers and pesticides. This allows farmers to use them without limitation. Therefore, these activities are potentially affecting water quality of the lake and its tributaries.

Similar to crop cultivation, livestock has a wide variety of functions and is a critical commodity of many households in the Lake Tana catchment. However, in Ethiopia as well as in the Lake Tana catchment, animals are not fenced, but are left free to graze on the communal lands such as wetlands. This could potentially cause environmental effects such as erosion, soil degradation, water pollution, and deforestation. For example, households in the Kurt Bahir Wetland allowed their livestock to graze on average for eight hours per day [43], which affects both the physical and biological components of the wetland through the consumption of plant biomass, trampling of plants, soil compaction and increasing nutrient input and bacterial contamination from their dung and urine.

### 4.2.2. Dam Construction

Dam construction for irrigation and hydropower purposes, has tremendous economic value and hence the practice is growing worldwide [44]. During the period of its growth transformation, Ethiopia planned to increase irrigated lands and energy supply [45]. This stimulated dam and hydropower plant construction from 2010 onwards. The Lake Tana watershed is identified as a region for significant irrigation development [45]. Currently, there are irrigation schemes including diversion weirs and large dams on more than 18 rivers. However, many dam construction projects are still planned on perennial tributaries of the lake, which could aggravate the effect on the state of the lake ecosystem. The Beles hydroelectric power plant (at the second outlet of the lake) [46] and the Megech-Seraba irrigation pump station are under construction, and intend to use water directly from the lake. This will have severe effects on the water volume of the lake, since 400 ha of land will be irrigated. This will subsequently affect the aquatic life, such as fish communities.

In sharp contrast to the policy principles and guidelines developed by the World Commission on Dams [44] and the International Hydropower Association [47], dams in the lake catchment are constructed in response to the emerging development needs only. Water resource developers are often unaware of the importance of fisheries and the impact of dam construction on fish. The co-ordination and collaboration between biologists and engineers is often lacking. Therefore, dam construction both for irrigation and hydropower purposes are potentially affecting the habitat and spawning ground of the fish species in the lake, leading to their stock reduction [11,48].

### 4.2.3. Urbanization and Waste Discharge

Currently, Ethiopia is rapidly urbanizing by a growth rate of 4.8% per year [49]. The development of urban areas is also the same in Amhara region. Of the 422 towns in the region, the majority are



encroaching on both sides of Lake Tana and are rapidly expanding. For example, to accommodate the growing social and economic needs, Bahir Dar, the capital of Amhara Region, has been rapidly expanding. This has resulted in lake-associated wetlands being transformed for different purposes such as streets, parking lots, hotels, lodges, industries and residences.

Besides wetland degradation, waste discharge into Lake Tana has become a serious and highly visible pressure. Waste management, both solid and liquid, in urban areas is unregulated. Consequently, all surface waters in the Lake Tana catchment are receiving untreated municipal and industrial wastes. Two-third of the households in Bahir Dar discharge waste into streets and floodwater drainages, which ultimately end up into Lake Tana or the Blue Nile River [50]. Besides household waste, the waste also originates from major institutions and industries including universities, factories, hotels, floriculture and hospitals which discharge their untreated waste into Lake Tana [51].

#### 4.2.4. Sand Mining and River Water Pumping

Sand mining in the watershed, a relatively recent phenomenon, is rapidly growing and expanding to all tributaries of the lake and as such, it is becoming an important pressure on the migratory *Labeobarbus* species [15]. Sand mining has direct effects on habitat and breeding ground degradation and it physically injures the fish. It also accelerates soil erosion, which results in siltation within the lake. The two ways of sand extraction in the inflowing rivers are filtering and digging [15]. The former is mainly practiced in the upstream areas during the rainy season, which is the period during which the peak spawning of the migratory *Labeobarbus* species takes place. Whereas, the latter is primarily executed at the river mouths during the dry season.

During fieldwork, we observed many small-scale farmer–level irrigation activities. Farmers undertake these activities either by directly pumping water from the perennial tributaries and streams or by building a barrier on the riverbed and divert the river water partly into their farming land. According to the local inhabitants, such kind of activities are very common in the entire lake catchment and they are considered as model practices being encouraged all around the country. Hence, these activities could have severe effect on the natural flow of the rivers and their biodiversity.

#### 4.2.5. Fisheries

Illegal fishing, which leads to increased fish harvesting, affects the aquatic ecosystem functioning as well as the sustainability of the fish stocks [52]. It likely affects the abundance, composition and growth of fish. The most destructive monofilaments, which are imported from Egypt through Sudan, were introduced into Lake Tana fisheries towards the end of 2000s. Currently, because of their perceived effectiveness in catching fish, more than 98% of fishers are using these gill nets [14]. Thus, illegal, uncontrolled and unreported (IUU) fishing in the lake is becoming a norm. Furthermore, legally banned fishing techniques such as fencing, castnets, and poisonous chemicals (crushed seeds of Birbra tree, *Millettia ferruginea* and DDT) are used in most of the lake tributaries.

### 4.3. State Changes

Lake Tana catchment is among the top 250 globally most important lake catchments for biodiversity. Wetlands in the Lake Tana catchment form the largest and ecologically main national wetland complex (24,000 ha, 1.6% of its watershed) [43]. These wetlands are unique bird hotspots. Because of this, the lake catchment is a globally recognized wintering site for migratory birds. Moreover, wetlands in the lake catchment are ideal breeding grounds and nursery sites for many fish species including genera *Afronemacheilus*, *Enteromius*, *Clarias*, *Garra*, *Labeobarbus* (i.e., *L. beso*) and *Oreochromis* [9,13,32]. They are also nursery sites for juveniles of the migratory *Labeobarbus* species.

However, land degradation, particularly wetlands degradation, has become an environmental disaster in Ethiopia [53]. Despite their socio-economic and ecological importance, many people in Ethiopia still consider wetlands solely as the breeding places for disease vectors like mosquitoes [54]. This perception makes the wetlands susceptible to degradation. The main reasons for Lake Tana

wetlands degradation are flood recession agriculture, urbanization, waste disposal, free grazing and removal of macrophytes [43,55]. *Cyperus papyrus*, the characteristic plant species of the wetlands, has dramatically declined, with even local extinctions in some areas [38]. Consequently, many wetlands in the lake catchment are shrinking at a drastic rate [43,56–58], (Table 2). This is an indication that the wetlands in the lake catchment are not wisely utilized in line with the Ramsar Convention. The negative effect of wetland degradation on diversity and abundance of macroinvertebrates has been described in previous studies [59,60].

The drastic land degradation and deforestation aggravates sedimentation in Lake Tana [1,41]. Despite the 0.48 million tons of sediments (32% of the gross sediment transported) being trapped annually by the floodplains (wetlands), 1.56 million tons of sediment is still being deposited into the lake each year [61] and this negatively affects the habitat and nursery sites of many fish species. Moreover, due to siltation and water pumping, many perennial rivers have now become seasonal to the detriment of the riverine and migratory fish species.

Nowadays, degradation of the physical-chemical characteristics of the Lake Tana ecosystem is intensifying. Due to both point and nonpoint pollutions, the lake water quality is rapidly changing [62]. This was confirmed after bacteriological and chemical pollutions of the lake were revealed near Bahir Dar City [8]. According to Goshu [63], fecal coliforms and *Escherichia coli* concentrations significantly increased and analysis of Biological Oxygen Demand (BOD5) indicated organic pollution [64] in the Gulf of Bahir Dar. Additionally, a high concentration of the cyanobacterial genus *Microcystis* [65] leading to eutrophication [66] was observed in the Gulf of Bahir Dar. According to a discussion with local fishers, the taste of the flesh of *O. niloticus*, which primary feeds on algae, seemed to have changed noticeably in 2012. A plausible explanation could have been the occurrence of high concentrations of cyanobacteria. Of some fish species in the lake, mercury levels exceed internationally accepted safe levels for consumption [67]. Ahrens et al. [68] also reported high concentration of perfluoroalkyl carboxylates such as PFCAs in water, sediment and fish of Lake Tana.

The world's most invasive aquatic weed, water hyacinth (*Eichhornia crassipes*), infested Lake Tana in 2011 [62]. The plausible reason could have been the changes in the physico-chemical characteristics of the lake. Currently, its coverage is estimated to be more than 20,000 hectares. Due to the rapid reproduction and the high capacity of water hyacinth to utilize nutrients, this species outcompetes the native species [69,70]. Consequently, it is massively affecting the biological and physical-chemical characteristics of Lake Tana [71–74]. Besides, water hyacinth causing evapo-transpiration from Lake Tana could most likely affect the flow of the Nile water. The negative effects of water hyacinth on ecosystem functions of many African lakes has been repeatedly reported [69,75,76]. Therefore, based on experiences in other African lakes and the rapid increasing distribution of water hyacinth in Lake Tana, there is little doubt that the effects of water hyacinth on Lake Tana fish and fisheries will become severe.

Development activities such as sand mining and dam construction for both irrigation and hydropower purposes undermine the biodiversity of the fish. They are creating immense pressures on survival of the lake fish, particularly on the migratory endemic *Labeobarbus* species. Dam constructions, for example, do not consider mitigation of fish [11]. At the Gelda and Shini Rivers, because of dam constructions, spawning grounds across 27 km and 22 km of the rivers are now inaccessible to the migratory *Labeobarbus* species [11]. The dam causes a large number of fish to be trapped and to be more susceptible to predators and illegal fishery. Also hydropower structures [77] and sand mining activities [15] are known to have immense impacts on fish. Many fishes from Lake Tana enter the hydropower structure of Tana Beles where they are exposed to severe risks of injury. Sand mining for dam and house construction purposes has various negative effects on spawning grounds of the migratory *Labeobarbus* species. Therefore, if the development projects in the lake's watershed are going to be fully implemented, without proper management, the lake water depth and area will be reduced by 0.44 m and 30 km<sup>2</sup>, respectively [78] and this will continue to cause declines of the fish stock. Subsequently, local extirpations of the endemic *Labeobarbus* species is anticipated.

**Table 2.** Trends of land use type, wetlands and lake size change in the Lake Tana watershed. (“-” refers to no data available.)

Catchment	Area (ha)	Year									
		1957	1973	1985	1986	1995	2002	2005	2008	2011	2013
Infranza [58]	Grass land	-	596	-	2656	2486	-	-	-	934	-
	Cultivation and settlement	-	4492	-	6280	8877	-	-	-	1.1177	-
	Bush land	-	1.7362	-	1.2772	1.2087	-	-	-	1.1024	-
	Forest	-	1492	-	3106	1302	-	-	-	1850	-
	Kurt Bahir wetland [43]		1580		1016	769	-		-	-	486
Gumarac [56]	Grass land	39634	-	1993	-	-	-	946		-	-
	Cultivation and settlement	1.10879	-	135	-	-	-	14.1888		-	-
	Bush land	1.2367	-	5179	-	-	-	1064		-	-
	Forest	1.9227	-	4633	-	-	-	2826		-	-
	Wetlands	970		383		-	-	267		-	-
Gilgel Abayd [57]	Grass land	-	16.2481	-	10.9550	9.1748	-	-	7.3026	-	-
	Cultivation and settlement	-	20.5993	-	27.4947	28.6261	-	-	32.4536	-	-
	Wood and bush land	-	2.4645	-	3.9980	6.0148	-	-	6.0863	-	-
	Forest	-	9328	-	4527	3298	-	-	2581	-	-
	Wetlands	-	8.4069	-	5.6465	4.5878	-	-	4.4419	-	-
Ribb & Gumarae [79]	Wetlands	-	2.5255	-	2.4982	-	-	-	1923	-	
Lake Tana [56]	Lake size	-	30.1899	-	30.2946	30.1082	-	-	28.2990	-	-

Illegal fishing in Lake Tana is massively contributing to the depletion of the lake's fish stocks [80]. Due to their spawning aggregation [13,32] and ecologically highly specialized endemics [81], Lake Tana *Labeobarbus* species are highly vulnerable to this effect. This can be best illustrated by the reduction in Catch Per Unit Effort (CPUE). The CPUE for the endemic *Labeobarbus* species has declined from 63 kg/trip in 1993 [80] to 6 kg/trip in 2010 [82]. Likewise, the CPUE for all the commercially important fish including *Labeobarbus* species has also declined from 177 kg/trip in 1993 to 56 kg/trip in 2010 [10].

Generally, when habitat and spawning ground degradations are severe, endemic species such as fish have a high chance of extinction. In light of the fact that Lake Tana is home to many endemic migratory fish including six threatened species, anthropogenic activities are detrimental to their stock. These activities can jeopardize the lake ecosystem, leading to severe reductions in productivity and ecosystem services. The overall impacts on the Lake Tana catchment have put the lake at risk. Thus, if degradation of the lake catchment continues at the present rate and measures are not urgently taken, extinction of some fish species is inevitable. The loss of fish is disastrous and those who are relying on its service (fishers) are the first to feel the impact. To avoid another repeat in history, lessons learnt from Lake Haromaya (a dried lake) and Lake Abijata (a rapidly declining lake), need to be incorporated into the national and regional fisheries management plan.

#### 4.4. Impacts

Fisheries in Lake Tana contribute to the livelihoods of fishers as food and an income source via employment. In Lake Tana, fishers are often poor and the income received from selling fish is the only option to provide them access to basic needs such as food, health, education and clothing. Moreover, the lake fisheries have various social and cultural benefits to the fishers. Since the nature of the fishing activity is often social, it strengthens the bond among the fishers. Fishers have a long history of social gathering such as "idir" and through this, they have been sharing knowledge, skills, culture and other assets.

However, the lake fisheries are highly vulnerable to external pressures and these are detrimental to their attributes. Consequently, these have various impacts on socio-economic values of the local inhabitants. In particular, the drastic reduction of fish populations [80], for example, negatively affects livelihoods of the fishers in Lake Tana.

Nowadays, thefts of fish products and fishing gear are on the rise in Lake Tana. This is most likely linked to the fish population reduction. Fishers and fisheries experts also corroborate this and point out that this was not the case until the early of 2000s prior to which fish production was deemed abundant. This situation has become the root cause for conflicts among the fishing community. As a result, it is negatively affecting the community cohesion. Due to this, many fishers have doubts regarding the continuity of their social and economic values. Therefore, policy makers should recognize the importance of fisheries for socio-economic values of the local inhabitants and should ensure its sustainability.

Additionally, health risks, due to contamination by pathogens coming from non-point and point sources of pollution, are wide reaching impacts in the lake catchment. The direct discharge of untreated waste into the lake negatively affected the water quality leading to algal blooms including harmful algae. The lake water pollution is therefore detrimental to many people who are directly fetching water from the lake for drinking and washing. The effect is worse for the fishers whose day-to-day activity is in the lake, and to many people particularly children who are swimming in the lake. Furthermore, mercury levels higher than the internationally accepted safe levels for consumption [67] and high concentration of the perfluoroalkyl carboxylates [68] in some fish species are a great health concern for fish consumers.

Water hyacinth is a suitable media for mosquito reproduction [74,83] and for snails, which serve as vector for the parasite of Schistosomiasis [84]. It also provides cover to reptiles such as poisonous snakes [70]. The occurrence of water hyacinth in Lake Victoria, for example, accounted for a larger proportion of the cholera cases in Kenya [85]. Therefore, based on experiences in other African countries, there is no doubt that the newly introduced and rapidly expanding water hyacinth in Lake Tana could be detrimental to the health of the local people.

## 5. Discussion

### 5.1. Potential Responses to Increase the Sustainability of Lake Tana

Many institutions share ownership of Lake Tana and its resources. There is no institution clearly responsible for management of Lake Tana and its resources [86]. Resources such as fish and wetlands are public goods. This makes it difficult to sustainably exploit these natural resources. The problem of shared or lack of ownership is clearly reflected when it comes to the management of the lake resources. For example, when an attempt was made to manage the water hyacinth, the issue of ownership made it difficult to address the responsible partners. Despite the reality that solving problems in Lake Tana appears to be very much dependent on institutional collaboration, the current cooperation among the institutions with a similar scope is weak [11]. These institutions do not communicate very well about conservation of the lake and its biodiversity. For example, although local universities and research institutions have conducted many studies on the fish species and the challenges they are facing, there is no organized system, in which these institutions co-operate and share their findings. Furthermore, sustainable management of the lake resources involves participation of the local communities and fishers in particular as main actors. However, in the Lake Tana watershed, cooperation between the concerned institutions and local communities is generally weak [11,38]. Despite the fact that a bottom-up and top-down approach is crucial during problem identification, decision-making and policy enforcement, merely a top-down approach has been implemented instead. For example, fishers have not been consulted during the development of fisheries regulations and their attitudes and perceptions towards the management and policy enforcement, which are vital for effective fisheries management, have not been considered and included in the environmental management (personal observation by the authors). Moreover, implementation of the national and regional proclamations such as the Federal Fish Resource Development and Utilization Proclamation, the Amhara Regional State Fisheries Proclamation, and the Fisheries Resource Development Protection and Utilization Proclamation Enforcement is lacking.

Thus, the lack of proper policy implementation, participation of the local communities and institutional collaborations are leading to ineffective fisheries management in the lake. A timely enforcement of the policy, a close co-operation and mutual support among governmental institutions that have a similar scope and the local communities is therefore crucial for conservation of the lake resources. To this end, we have identified viable multilevel responses including, family planning, policy revision and proper implementation of wastewater treatment plants, habitat restoration and subsidizing stakeholders as feedback to driving forces, pressures, changes of state and impacts. More explanation about the responses is presented in the DPSIR framework (Figure 3). Besides, ecotourism development helps to reduce pressures on the natural resources through diversification of livelihoods. The Lake Tana watershed has various key destinations for ecotourism development including biodiversity hotspots, natural forests, monasteries and wetlands. The rich natural resources coupled with the unique cultures and histories of the local communities provide a foundation for ecotourism development. As a result, more than 84,000 local and international visitors travel to the watershed each year, substantiating the potential of Lake Tana as emergent destination [38]. This can make the local people aware of the importance of protecting and conserving natural resources. Therefore, it is very crucial to integrate ecotourism development into the sustainable management of the Lake Tana fish resources. Furthermore, we have described the major threats of the lake ecosystem and their potential management options (Table 3). To help facilitate conservation of the resources, we also suggested that the responsible organization(s)/communities should address these issues (Table 3). Hence, each organization and the community should take their responsibility and strengthen their co-operation. Furthermore, we have described several research issues in ecology and fisheries, which require further investigation. The main research gaps are related to: (1) the ecosystem services of wetlands in the lake watershed and the consequence of their degradation for biodiversity, (2) impacts of the rapidly declining *Labeobarbus* species particularly the piscivorous species on food web of Lake

Tana, (3) quantitative estimation of the effects of development activities on both biodiversity loss and environmental degradation particularly the lake water quality, (4) the ecological and socioeconomic impacts of water hyacinth in the lake, (5) potential of the native plants to out-compete water hyacinth, (6) overall as well as species based contribution of Lake Tana fisheries to the local livelihood and regional economy, and (7) scientific and feasible recommendations regarding suitable fish migration designs for the migratory *Labeobarbus* species. Therefore, the local universities and research institutions in collaboration with other institutions should take the responsibility to resolve the research gaps and to combat the conservation challenges of the Lake Tana fish resources.

**Table 3.** A description of the major anthropogenic threats in the Lake Tana catchment and their optimal solutions and the responsible organizations/community. For proper implementation of these solutions, the available policies should be revised and properly implemented. In addition, budget has to be supported by the local Government and NGOs.

Major Threats	Possible Solutions (Responses)	Possible Actors
Illegal fishing	Stop illegal fishing	Fishers Local Government
	License fishers	
	Limitation of the total amount of landing sites	
	Establishment of fisheries database and standardized data acquisition protocols	
	Strengthen fisheries associations	
	Hire fisheries inspectors	
Agriculture	Subsidize fishers (e.g., make legal gill nets available at a reasonable price)	Farmers  Local Government and farmers
	Stop flood recession agriculture	
	Stop illegal deforestation	
	Limitation of fertilizers and pesticides use	
Dam construction	Reforestation	Local Government
	Soil and water conservation	
	Alternative livelihoods (e.g., community-based ecotourism)	
Waste (water) discharge	Environmental impact assessment	Local Government
	Stakeholder involvement (i.e., starting from the grassroots activities)	
Waste (water) discharge	Proper design (e.g., include fish ways)	Owners of business centers (i.e., hotels, industries, factories, hospitals, schools and colleges) and local Government
	Waste treatment (e.g. use constructed wetlands or waste treatment plants)	
	Waste recycling	
Water hyacinth	Mechanical and biological control	Local Government
	Economical exploitation of water hyacinth (e.g., to make handcraft)	
Sand mining	Manual removal	Local Government and local people
	Identification of mining sites (e.g., exclude ideal spawning grounds of the migratory fish and main habitat of other biodiversity)	
	License sand miners	
	Limitation of mining seasons	
	Alternative livelihoods (e.g., community-based ecotourism)	

## 5.2. General Discussion

Globally, freshwater resources have been affected by human induced activities causing biodiversity loss and hydro-morphological alterations. These changes also impact people, which are depending on these resources. The anthropogenic impacts still remain major challenges in many parts of the world [87]. Due to the rapid increase in human population leading to various pressures, the fish communities in many African lakes such as Lake Malawi, Lake Tanganyika and Lake Victoria have markedly declined [88,89].

Ethiopia has abundant surface inland water resources harboring an impressive diversity of fish species. However, human population is rapidly increasing, while natural resources remain limited.

As a result, the use of the available resources has been intensified and has led to overexploitation. Activities such as overfishing, land degradation and environmental pollution have negative impacts on survival of fish species. In many cases, wastes are discharged indiscriminately into the nearby waterbodies without any treatment, intensifying the Ethiopian water resources problems [90]. This is not different from Lake Tana, Ethiopia's largest lake, where fish communities are rapidly declining due to anthropogenic activities [1,10,11]. Illegal fishing coupled with environmental degradation has already led to drastic stock reduction of the endemic *Labeobarbus* species. The fish stock reduction has very serious implications on the lives of thousands of people who are strongly dependent on fish communities. For sustainability of the lake fisheries, implementation of the environmental management is vital.

Fisheries management is virtually lacking in Lake Tana. This is because the managers and policy makers, who are responsible for biodiversity conservation, underestimate the importance of the lake fish and fisheries to the local economy and residents. Additionally, the collaboration between scientists and managers or policy makers is poor and the available knowledge on Lake Tana fish and fisheries is not distributed enough to managers and policy makers.

The DPSIR framework is a useful tool to comprehensively organize the available information in a meaningful way for use by fisheries managers and policy makers. As a result, it has been widely used to identify the major fisheries problems, adopt standardized indicators, improve fisheries management and guide management decisions [21,91–93]. Therefore, its application in the Lake Tana catchment will help to bridge the communication gap among stakeholders and provide decision makers with scientifically underbuilt information.

Nevertheless, it also has some limitations. These are related to terminological unclarity, lack of methodological description to analyze disturbances and oversimplification of problems when dealing with complex environmental issues [21,94,95]. These limitations can be overcome by integrating it with other conceptual frameworks [94,95] and more specific modelling tools [96]. Although the DPSIR framework has particular limitations, it has for many cases shown to be an effective tool to summarize and visualize the cause-effect relationships between environmental components and anthropogenic impacts, and is a first step to define and trade-off responses at different levels of the impact chain.

## 6. Conclusions

The local scientific community urgently needs to be informed about the severe fish abundance reduction in Lake Tana and its consequences. Preventive measures must be initiated now, before extinction of some species occur. We should implement lessons learned from experiences elsewhere such as Lake Haromaya, Lake Abijata and Lake Victoria. The conservation challenges of the Lake Tana fisheries must be addressed for the general health of the ecosystem and its users. In order to support the conservation practices, we have summarized and visualized the cause-effect interactions between human pressures and the environmental components in a manner familiar to fisheries managers and policy makers using the DPSIR framework. Thus, this helps to bridge the gap between research and decision-making in the lake catchment. The Ministries of Agriculture and Livestock Resources and all other concerned authorities, therefore, should incorporate the developed conceptual frameworks into the Lake Tana fish resources management plan. As overfishing and environmental degradations are common in many African freshwater bodies, this document can also serve as a reference for the application of DPSIR in these freshwater bodies.

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## References

1. Getahun, A.; Dejen, E. *Fishes of Lake Tana: A Guide Book*; Addis Ababa University Press: Addis Ababa, Ethiopia, 2012.
2. Prokofiev, A.M.; Golubtsov, A.S. Revision of the loach genus *Afronemacheilus* (Teleostei: Balitoridae: Nemacheilinae) with description of a new species from the Omo-Turkana basin, Ethiopia. *Ichthyol. Explor. Freshw.* **2013**, *24*, 1–14.
3. Dejen, E.; Osse, J.W.; Sibbing, F.A. Ecological position of ‘small barbs’ and their potential for fisheries: An option to reduce fishing pressure on ‘large barbs’ of Lake Tana (Ethiopia)? *Aquat. Ecosyst. Health Manag.* **2003**, *6*, 337–342. [[CrossRef](#)]
4. Getahun, A. *Systematic Studies of the African Species of the Genus Garra (Pisces: Cyprinidae)*; City University of New York: New York, NY, USA, 2000.
5. Nagelkerke, L.A.; Sibbing, F.A. The large barbs (*Barbus* spp., Cyprinidae, Teleostei) of Lake Tana (Ethiopia), with a description of a new species, *Barbus osseensis*. *Neth. J. Zool.* **2000**, *50*, 179–214. [[CrossRef](#)]
6. Vreven, E.; Musschoot, T.; Snoeks, J.; Schliewen, U.K. The African hexaploid Torini (Cypriniformes: Cyprinidae): Review of a tumultuous history. *Zool. J. Linn. Soc.* **2016**, *177*, 231–305. [[CrossRef](#)]
7. Nagelkerke, L.A.J.; Sibbing, F.A. Reproductive segregation among the *Barbus intermedius* complex of Lake Tana, Ethiopia. An example of intralacustrine speciation? *J. Fish Biol.* **1996**, *49*, 1244–1266. [[CrossRef](#)]
8. Vijverberg, J.; Sibbing, F.A.; Dejen, E. Lake Tana: Source of the Blue Nile. In *The Nile*; Dumont, H.J., Ed.; Springer: Dordrecht, The Netherlands, 2009; pp. 163–192.
9. Anteneh, W.; Getahun, A.; Dejen, E.; Sibbing, F.A.; Nagelkerke, L.A.J.; De Graaf, M.; Wudneh, T.; Vijverberg, J.; Palstra, A.P. Spawning migrations of the endemic *Labeobarbus* (Cyprinidae, Teleostei) species of Lake Tana, Ethiopia: Status and threats. *J. Fish Biol.* **2012**, *81*, 750–765. [[CrossRef](#)] [[PubMed](#)]
10. Dejen, E.; Anteneh, W.; Vijverberg, J. The Decline of the Lake Tana (Ethiopia) Fisheries: Causes and Possible Solutions. *Land Degrad. Dev.* **2017**, *28*, 1842–1851. [[CrossRef](#)]
11. Gebremedhin, S.; Getahun, A.; Anteneh, W.; Gedif, B.; Gashu, B.; Tefera, B.; Berhanie, Z.; Alemaw, D. Effect of large weirs on abundance and diversity of migratory *Labeobarbus* species in tributaries of Lake Tana, Ethiopia. *Afr. J. Aquat. Sci.* **2017**, *42*, 369–373.
12. Nagelkerke, L.A.; Mina, M.V.; Wudneh, T.; Sibbing, F.A.; Osse, J.W. In Lake Tana, a unique fish fauna needs protection. *Bioscience* **1995**, *45*, 772–775.
13. De Graaf, M.; Nentwich, E.D.; Osse, J.W.M.; Sibbing, F.A. Lacustrine spawning: Is this a new reproductive strategy among ‘large’ African cyprinid fishes? *J. Fish Biol.* **2005**, *66*, 1214–1236. [[CrossRef](#)]
14. Asfaw, K. *Assessment of Reed Boat Fishery in the Northern Part of Lake Tana*; Bahir Dar University: Bahir Dar, Ethiopia, 2013.
15. Mingist, M.; Gebremedhin, S. Could sand mining be a major threat for the declining endemic *Labeobarbus* species of Lake Tana, Ethiopia? *Singap. J. Trop. Geogr.* **2016**, *37*, 195–208. [[CrossRef](#)]
16. Ogden, J.C.; Davis, S.M.; Jacobs, K.J.; Barnes, T.; Fling, H.E. The use of conceptual ecological models to guide ecosystem restoration in South Florida. *Wetlands* **2005**, *25*, 795–809. [[CrossRef](#)]
17. Sekovski, I.; Newton, A.; Dennison, W.C. Megacities in the coastal zone: Using a driver-pressure-state-impact-response framework to address complex environmental problems. *Estuar. Coast. Shelf Sci.* **2012**, *96*, 48–59. [[CrossRef](#)]
18. Smith, C.; Papadopoulou, N.; Barnard, S.; Mazik, K.; Patrício, J.; Elliott, M.; Solaun, O.; Little, S.; Borja, A.; Bhatia, N. *Conceptual Models for the Effects of Marine Pressures on Biodiversity*; Deliverable 1.1; Hellenic Centre for Marine Research: Attiki, Greece, 2014.
19. Gabrielsen, P.; Bosch, P. *Environmental Indicators: Typology and Use in Reporting*; EEA: Copenhagen, Denmark, 2003.
20. OECD. *Environmental Indicators: Development, Measurement and Use*; Reference Paper; OECD: Paris, France, 2003.



21. Martins, J.H.; Camanho, A.S.; Gaspar, M.B. A review of the application of driving forces-Pressure-State-Impact-Response framework to fisheries management. *Ocean Coast. Manag.* **2012**, *69*, 273–281. [[CrossRef](#)]
22. Agyemang, I.; McDonald, A.; Carver, S. *Application of the DPSIR Framework to Environmental Degradation Assessment in Northern Ghana*; Natural Resources Forum; Wiley Online Library: Hoboken, NJ, USA, 2007; pp. 212–225.
23. Ojeda-Martínez, C.; Casalduero, F.G.; Bayle-Sempere, J.T.; Cebrian, C.B.; Valle, C.; Sanchez-Lizaso, J.L.; Forcada, A.; Sanchez-Jerez, P.; Martín-Sosa, P.; Falcón, J.M. A conceptual framework for the integral management of marine protected areas. *Ocean Coast. Manag.* **2009**, *52*, 89–101. [[CrossRef](#)]
24. Mohr, P.A. *The Geology of Ethiopia*; Haile Selassie I University Press: Addis Ababa, Ethiopia, 1971.
25. Awulachew, S.B.; Yilma, A.D.; Loulseged, M.; Loiskandl, W.; Ayana, M.; Alamirew, T. *Water Resources and Irrigation Development in Ethiopia*; IWMI: Colombo, Sri Lanka, 2007; Volume 123.
26. Wondie, A. Improving management of shoreline and riparian wetland ecosystems: The case of Lake Tana catchment. *Ecohydrol. Hydrobiol.* **2010**, *10*, 123–131. [[CrossRef](#)]
27. Tscherning, K.; Helming, K.; Krippner, B.; Sieber, S.; Paloma, S.G. Does research applying the DPSIR framework support decision making? *Land Use Policy* **2012**, *29*, 102–110. [[CrossRef](#)]
28. Lewison, R.L.; Rudd, M.A.; Al-Hayek, W.; Baldwin, C.; Beger, M.; Lieske, S.N.; Jones, C.; Satumanatpan, S.; Junchompoo, C.; Hines, E. How the DPSIR framework can be used for structuring problems and facilitating empirical research in coastal systems. *Environ. Sci. Policy* **2016**, *56*, 110–119. [[CrossRef](#)]
29. Miller, J.W.; Kocovsky, P.M.; Wiegmann, D.; Miner, J.G. Fish Community Responses to Submerged Aquatic Vegetation in Maumee Bay, Western Lake Erie. *N. Am. J. Fish Manag.* **2018**. [[CrossRef](#)]
30. Snoeks, J.; Laleye, P.; Getahun, A.; Contreras-MacBeath, T. *Labeobarbus macropthalmus*. In *The IUCN Red List of Threatened Species*; International Union for Conservation of Nature and Natural Resources: Gland, Switzerland, 2010.
31. Nagelkerke, L.A.J. *The Barbs of Lake Tana, Ethiopia: Morphological Diversity and Its Implications for Taxonomy, Trophic Resource Partitioning, and Fisheries*; Wageningen University: Wageningen, The Netherlands, 1997.
32. Palstra, A.P.; De Graaf, M.; Sibbing, F.A. Riverine spawning and reproductive segregation in a lacustrine cyprinid species flock, facilitated by homing? *Anim. Biol.* **2004**, *54*, 393–415. [[CrossRef](#)]
33. Dejen, E.; Vijverberg, J.; Nagelkerke, L.A.J.; Sibbing, F.A. Growth, biomass, and production of two small barbs (*Barbus humilis* and *B. tanapelagi*, *Cyprinidae*) and their role in the food web of Lake Tana (Ethiopia). *Hydrobiologia* **2009**, *636*, 89–100. [[CrossRef](#)]
34. Wudneh, T. *Biology and Management of Fish Stocks in Bahir Dar Gulf, Lake Tana, Ethiopia*; Wageningen University: Wageningen, The Netherlands, 1998.
35. Gebremedhin, S.; Budusa, M.; Mingist, M.; Vijverberg, J. Determining factors for fishers' income: The case of Lake Tana, Ethiopia. *Int. J. Curr. Res.* **2013**, *5*, 1182–1186.
36. Downing, A.; van Nes, E.; Balirwa, J.; Beuving, J.; Bwathondi, P.; Chapman, L.; Cornelissen, I.; Cowx, I.; Goudswaard, K.; Hecky, R. Coupled human and natural system dynamics as key to the sustainability of Lake Victoria's ecosystem services. *Ecol. Soc.* **2014**, *19*, 31. [[CrossRef](#)]
37. De Graaf, M.; Machiels, M.A.M.; Wudneh, T.; Sibbing, F.A. Declining stocks of Lake Tana's endemic *Barbus* species flock (*Pisces, Cyprinidae*): Natural variation or human impact? *Biol. Conserv.* **2004**, *116*, 277–287. [[CrossRef](#)]
38. Zur Heide, F. *Feasibility Study for a Lake Tana Biosphere Reserve, Ethiopia*; Bundesamt für Naturschutz, BfN: Bonn, Germany, 2012.
39. Anteneh, M. Demographic Characteristics of the Lake Tana Basin. In *Social and Ecological System Dynamics*; Springer: Berlin, Germany, 2017; pp. 283–292.
40. Commission, N.P. *The Second Growth and Transformation Plan (GTP II) (2015/16-2019/20) (Draft)*; The Federal Democratic Republic of Ethiopia: Addis Ababa, Ethiopia, 2015.
41. Karlberg, L.; Hoff, H.; Amsalu, T.; Andersson, K.; Binnington, T.; Flores-López, F.; de Bruin, A.; Gebrehiwot, S.G.; Gedif, B.; Johnson, O. Tackling complexity: Understanding the food-energy-environment nexus in Ethiopia's Lake tana sub-basin. *Water Altern.* **2015**, *8*, 710–734.
42. Ministry of Finance and Economic Development. *Growth and Transformation Plan (GTP)*; Ministry of Finance and Economic Development: Addis Ababa, Ethiopia, 2010.

43. Gebremedhin, S.; Mingist, M.; Melak, T.; Tsegaye, T.; Mequanint, F. Land use change and its drivers in Kurt Bahir wetland, north-western Ethiopia. *Afr. J. Aquat. Sci.* **2017**, *42*, 45–54.
44. WCD. *Dams and Development: A New Framework for Decision-Making, Overview of the Report by the World Commission on Dams*; WCD: London, UK, 2000.
45. McCartney, M.; Alemayehu, T.; Shiferaw, A.; Awulachew, S. *Evaluation of Current and Future Water Resources Development in the Lake Tana Basin, Ethiopia*; IWMI: Colombo, Sri Lanka, 2010; Volume 134.
46. Goor, Q.; Halleux, C.; Mohamed, Y.; Tilmant, A. Optimal operation of a multipurpose multireservoir system in the Eastern Nile River Basin. *Hydrol. Earth Syst. Sci.* **2010**, *14*, 1895. [[CrossRef](#)]
47. IHA. *The Role of Hydropower in Sustainable Development*; IHA White Paper; IHA: Ann Arbor, MI, USA, 2003.
48. Anteneh, W.; Getahun, A.; Dejen, E. Spawning migrations of Lake Tana *Labeobarbus* spp. (*Teleostei: Cyprinidae*) in the Ribb River, Ethiopia. *Afr. J. Aquat. Sci.* **2013**, *38*, 61–68. [[CrossRef](#)]
49. Gebreegziabher, G. Urban Areas and Planning in the Lake Tana Region. In *Social and Ecological System Dynamics*; Springer: Berlin, Germany, 2017; pp. 417–429.
50. Mekonnen, F.H. Liquid waste management: The case of Bahir Dar, Ethiopia. *Ethiop. J. Health Dev.* **2012**, *26*, 49–53.
51. Mehari, A.K.; Gebremedhin, S.; Ayele, B. Effects of bahir dar textile factory effluents on the water quality of the head waters of Blue Nile River, Ethiopia. *Int. J. Anal. Chem.* **2015**, *2015*, 905247. [[CrossRef](#)] [[PubMed](#)]
52. Lindley, J.; Techera, E.J. Overcoming complexity in illegal, unregulated and unreported fishing to achieve effective regulatory pluralism. *Mar. Policy* **2017**, *81*, 71–79. [[CrossRef](#)]
53. Delelegn, Y.; Geheb, K. *Wetlands of Ethiopia: Proceedings of a Seminar on the Resources and Status of Ethiopia's Wetlands*; IUCN: Nairobi, Kenya, 2003.
54. EWNRA. Creating National Commitment for Wetland policy and Strategy Development in Ethiopia. In Proceedings of the National Stake Holder's Workshop on Conservation and Management Issues of Abjiata-Shala Lakes National Park, Addis Ababa, Ethiopia, 15 July 2008; Fekadu, T., Rozenom, A., Eds.; EWNRA: Addis Ababa, Ethiopia, 2008; pp. 18–19.
55. Gezie, A.; Anteneh, W.; Dejen, E.; Mereta, S.T. Effects of human-induced environmental changes on benthic macroinvertebrate assemblages of wetlands in Lake Tana Watershed, Northwest Ethiopia. *Environ. Monit. Assess.* **2017**, *189*, 152. [[CrossRef](#)] [[PubMed](#)]
56. Minale, A.S. Retrospective analysis of land cover and use dynamics in Gilgel Abbay Watershed by using GIS and remote sensing techniques, Northwestern Ethiopia. *Int. J. Geosci.* **2013**, *4*, 1003. [[CrossRef](#)]
57. Worku, G. Assessment on the Shrinkage and Ecological Importance of Wetlands of Fogera Plain, North West Ethiopia. *J. Environ. Earth Sci.* **2014**, *4*, 25–31.
58. Sewnet, A. Land use/cover change at Infraz watershed by using GIS and remote sensing techniques, northwestern Ethiopia. *Int. J. River Basin Manag.* **2015**, *14*, 133–142. [[CrossRef](#)]
59. Getachew, M.; Ambelu, A.; Tiku, S.; Legesse, W.; Adugna, A.; Kloos, H. Ecological assessment of Cheffa Wetland in the Borkena Valley, northeast Ethiopia: Macroinvertebrate and bird communities. *Ecol. Indic.* **2012**, *15*, 63–71. [[CrossRef](#)]
60. Mereta, S.T.; Boets, P.; De Meester, L.; Goethals, P.L. Development of a multimetric index based on benthic macroinvertebrates for the assessment of natural wetlands in Southwest Ethiopia. *Ecol. Indic.* **2013**, *29*, 510–521. [[CrossRef](#)]
61. Lemma, H.; Dessie, M.; Fentie, D.; Jean, P.; Lanckriet, S.; Adgo, E.; Nyssen, J. *Sediment Budget Including the Role of floodplains: The Case of Lake Tana Basin, Ethiopia, Tropical Lakes in a Changing Environment: Water, Land, Biology, Climate and Humans, Bahir Dar, Ethiopia*; Nyssen, J., Adgo, E., Dessie, M., Eds.; Bahir Dar University: Bahir Dar, Ethiopia, 2015.
62. Wondie, A.; Molla, E.; Goshu, G.; Gebrekidan, W.; Shibabaw, A.; Tewabe, D.; Genanew, G. Preliminary Survey of Water hyacinth in Lake Tana, Wetlands for Sustainable Development and Climate Change Mitigation. In Proceedings of the 2nd National Workshop, Bahir Dar, Ethiopia, 6 February 2012; Mengstu, S., Fetahi, T., Eds.; Ethiopian Fisheries and Aquatic Science Association: Bahir Dar, Ethiopia, 2012.
63. Goshu, G. *Annual Report on Lake Tana Water Quality Base Line Monitoring*; Tana Beles Integrated Water Resources Development Project; Bahir Dar University: Bahir Dar, Ethiopia, 2011.
64. Goshu, G.; Koelmans, A.; de Klein, J. Water Quality of Lake Tana Basin, Upper Blue Nile, Ethiopia. A Review of Available Data. In *Social and Ecological System Dynamics*; Krystyna, S., Goshu, G., Aynalem, S., Eds.; Springer: Basel, Switzerland, 2017; pp. 127–141.

65. Mankiewicz-Boczek, J.; Gagala, I.; Jurczak, T.; Urbaniak, M.; Negussie, Y.Z.; Zalewski, M. Incidence of microcystin-producing cyanobacteria in Lake Tana, the largest waterbody in Ethiopia. *Afr. J. Ecol.* **2015**, *53*, 54–63. [CrossRef]
66. Moges, M.A.; Tilahun, S.A.; Ayana, E.K.; Moges, M.M.; Gabye, N.; Giri, S.; Steenhuis, T.S. Non-Point Source Pollution of Dissolved Phosphorus in the Ethiopian Highlands: The Awramba Watershed Near Lake Tana. *Clean-Soil Air Water* **2016**, *44*, 703–709. [CrossRef]
67. Habiba, G.; Abebe, G.; Bravo, A.G.; Ermias, D.; Staffan, A.; Bishop, K. Mercury Human Exposure in Populations Living Around Lake Tana (Ethiopia). *Biol. Trace Elem. Res.* **2017**, *175*, 237–243. [CrossRef] [PubMed]
68. Ahrens, L.; Gashaw, H.; Sjöholm, M.; Gebrehiwot, S.G.; Getahun, A.; Derbe, E.; Bishop, K.; Akerblom, S. Poly- and perfluoroalkylated substances (PFASs) in water, sediment and fish muscle tissue from Lake Tana, Ethiopia and implications for human exposure. *Chemosphere* **2016**, *165*, 352–357. [CrossRef] [PubMed]
69. Gichuki, J.; Omondi, R.; Boera, P.; Okorut, T.; Matano, A.S.; Jembe, T.; Ofulla, A. Water Hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach dynamics and succession in the Nyanza Gulf of Lake Victoria (East Africa): Implications for water quality and biodiversity conservation. *Sci. World J.* **2012**, *2012*, 106429. [CrossRef] [PubMed]
70. Patel, S. Threats, management and envisaged utilizations of aquatic weed *Eichhornia crassipes*: An overview. *Rev. Environ. Sci. Bio/Technol.* **2012**, *11*, 249–259. [CrossRef]
71. Anteneh, W.; Tewabe, D.; Assefa, A.; Zeleke, A.; Tenaw, B.; Wassie, Y. *Water Hyacinth Coverage Survey Report on Lake Tana Biosphere Reserve*; Technical Report Series 2; Bahir Dar University: Bahir Dar, Ethiopia, 2015. Available online: [http://www.bdu.edu.et/scee/sites/default/files/Water%20hacintosh\\_Lake%20Tana\\_Report%20Series%202.pdf](http://www.bdu.edu.et/scee/sites/default/files/Water%20hacintosh_Lake%20Tana_Report%20Series%202.pdf) (accessed on 19 March 2018).
72. Getnet, B. *Impact of Water Hyacinth (Eichornia crassipes) on Water Quality of Lake Tana*; Bahir Dar University: Bahir Dar, Ethiopia, 2013.
73. Gedefaw, T. *Effect of Water Hyacinth (Eichornia crassipes) on Juvenile Fishes of Lake Tana*; Bahir Dar University: Bahir Dar, Ethiopia, 2014.
74. Gezie, A.; Assefa, W.W.; Getnet, B.; Anteneh, W.; Dejen, E.; Mereta, S.T. Potential impacts of water hyacinth invasion and management on water quality and human health in Lake Tana watershed, Northwest Ethiopia. In *Biological Invasions*; Springer: Berlin, Germany, 2018; pp. 1–18.
75. Kateregga, E.; Sterner, T. Lake Victoria fish stocks and the effects of water hyacinth. *J. Environ. Dev.* **2009**, *18*, 62–78. [CrossRef]
76. Mujingni, C. Quantification of the Impacts of Water Hyacinth on Riparian Communities in Cameroon and Assessment of an Appropriate Method of Control: The Case of the River Wouri Basin: The Case of the Wouri River Basin. Master's Dissertation, World Maritime University, Malmö, Sweden, 2012.
77. Mueller, M.; Pander, J.; Geist, J. Evaluation of external fish injury caused by hydropower plants based on a novel field-based protocol. *Fish. Manag. Ecol.* **2017**, *24*, 240–255. [CrossRef]
78. Alemayehu, T.; McCartney, M.; Kebede, S. The water resource implications of planned development in the Lake Tana catchment, Ethiopia. *Ecolhydrol. Hydrobiol.* **2010**, *10*, 211–221. [CrossRef]
79. Wubie, M.A.; Assen, M.; Nicolau, M.D. Patterns, causes and consequences of land use/cover dynamics in the Gumara watershed of Lake Tana Basin, Northwestern Ethiopia. *Environ. Syst. Res.* **2016**, *5*, 8. [CrossRef]
80. De Graaf, M.; van Zwieten, P.A.M.; Machiels, M.A.M.; Lemma, E.; Wudneh, T.; Dejen, E.; Sibbing, F.A. Vulnerability to a small-scale commercial fishery of Lake Tana's (Ethiopia) endemic *Labeobarbus* compared with African catfish and Nile tilapia: An example of recruitment-overfishing? *Fish. Res.* **2006**, *82*, 304–318. [CrossRef]
81. De Graaf, M.; Dejen, E.; Osse, J.W.M.; Sibbing, F.A. Adaptive radiation of Lake Tana's (Ethiopia) *Labeobarbus* species flock (Pisces, Cyprinidae). *Mar. Freshw. Res.* **2008**, *59*, 391–407. [CrossRef]
82. Mohammed, B.; de Graaf, M.; Nagelkerke, L.; Mingist, M. Assessment of motorized commercial gillnet fishery of the three commercially important fishes in Lake Tana. In Proceedings of the Ethiopian Fisheries and Aquatic Sciences Association (EFASA), Addis Ababa, Ethiopia, 14 March 2013.
83. Minakawa, N.; Sonye, G.; Dida, G.O.; Futami, K.; Kaneko, S. Recent reduction in the water level of Lake Victoria has created more habitats for *Anopheles funestus*. *Malar. J.* **2008**, *7*, 119. [CrossRef] [PubMed]
84. Borokoni, T.; Babalola, F. Management of invasive plant species in Nigeria through economic exploitation: Lessons from other countries. *Manag. Biol. Invasions* **2012**, *3*, 45–55. [CrossRef]

85. Feikin, D.R.; Tabu, C.W.; Gichuki, J. Does water hyacinth on East African lakes promote cholera outbreaks? *Am. J. Trop. Med. Hyg.* **2010**, *83*, 370–373. [[CrossRef](#)] [[PubMed](#)]
86. Goshu, G.; Aynalem, S. Problem Overview of the Lake Tana Basin. In *Social and Ecological System Dynamics*; Springer: Berlin, Germany, 2017; pp. 9–23.
87. Søndergaard, M.; Jeppesen, E. Anthropogenic impacts on lake and stream ecosystems, and approaches to restoration. *J. Appl. Ecol.* **2007**, *44*, 1089–1094. [[CrossRef](#)]
88. Ogutu-Ohwayo, R. The decline of the native fishes of lakes Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, *Lates niloticus*, and the Nile tilapia, *Oreochromis niloticus*. *Environ. Biol. Fish.* **1990**, *27*, 81–96. [[CrossRef](#)]
89. Lowe-McConnell, R. Recent research in the African Great Lakes: Fisheries, biodiversity and cichlid evolution. In *Proceedings of the Freshwater Forum, Dushanbe, Tajikistan, 29 August–1 September 2003*; Volume 20.
90. De Troyer, N.; Mereta, S.T.; Goethals, P.L.; Boets, P. Water quality assessment of streams and wetlands in a fast growing east African city. *Water* **2016**, *8*, 123. [[CrossRef](#)]
91. Knudsen, S.; Zengin, M.; Koçak, M.H. Identifying drivers for fishing pressure. A multidisciplinary study of trawl and sea snail fisheries in Samsun, Black Sea coast of Turkey. *Ocean Coast. Manag.* **2010**, *53*, 252–269. [[CrossRef](#)]
92. Mangi, S.C.; Roberts, C.M.; Rodwell, L.D. Reef fisheries management in Kenya: Preliminary approach using the driver-pressure-state-impacts-response (DPSIR) scheme of indicators. *Ocean Coast. Manag.* **2007**, *50*, 463–480. [[CrossRef](#)]
93. Kelble, C.R.; Loomis, D.K.; Lovelace, S.; Nuttle, W.K.; Ortner, P.B.; Fletcher, P.; Cook, G.S.; Lorenz, J.J.; Boyer, J.N. The EBM-DPSER conceptual model: Integrating ecosystem services into the DPSIR framework. *PLoS ONE* **2013**, *8*, e70766. [[CrossRef](#)] [[PubMed](#)]
94. Vannevel, R. Using DPSIR and Balances to Support Water Governance. *Water* **2018**, *10*, 118. [[CrossRef](#)]
95. Patrício, J.; Elliott, M.; Mazik, K.; Papadopoulou, K.-N.; Smith, C.J. DPSIR—Two decades of trying to develop a unifying framework for marine environmental management? *Front. Mar. Sci.* **2016**, *3*, 177. [[CrossRef](#)]
96. Nguyen, T.; Everaert, G.; Boets, P.; Forio, M.; Bennetsen, E.; Volk, M.; Hoang, T.; Goethals, P. Modelling tools to analyse and assess the ecological impact of hydropower dams. *Water* **2018**, *10*, 259. [[CrossRef](#)]



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