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On the Impact of Brazil's Largest Recent Oil Spill on Regional Oceans

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ABSTRACT

In 2019, an oil spill in Brazil, of unknown origin, severely impacted coastal environs with the worst environmental disaster ever recorded in any tropical coastal region globally severely damaging South Pirangi Reef area in the state of Rio Grande do Norte (RN). Here we discuss acute and chronic impacts including chemical contamination and economic consequences all over the world and show some evidence of the oil spill in this biodiverse area. Moreover, the lapse between the moment of the disaster, and the action to manage it, was hampered by a political agenda coinciding with local and global tragedies that redirected public attention. Meanwhile almost 2 years have passed still without the offending party identification or culpability; and poor communities may continue to absorb its deleterious impacts for decades without consideration or compensation. This disaster occurred during the Brazilian government's current issues involving extensive environmental mismanagement, resulting in a slow response from an inept system. It is with urgent necessity to spotlight this tragedy in this unique and sensitive reef habitat experiencing the ongoing damaging effects that include socio-economic losses not yet addressed.

1. Introduction

In late July 2019, Brazil passively witnessed its first major oil spill disaster, quickly reaching about 3000 km of the country's northeast coast [1-5], which holds one of the main marine diversity areas in the South Atlantic [6]. Although the peak of the spill seems to have been in September [7], the oil arrived on beaches and in estuaries until

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at least the end of 2019 (Figure 1). Due to currents, local hydrodynamics and geography, the oil quickly spread into a north and a south branch [8], traveling via the subsurface (between 50 cm and 1 m deep). It reached at least nine northeastern states [9] affecting about 55 marine protected areas [3]. To a lesser extent, the oil also arrived at two additional states in the southeast of Brazil. Such an impact, duration and extension explain why this spill is considered the worst environmental oil disaster ever recorded in tropical coastal regions [3].

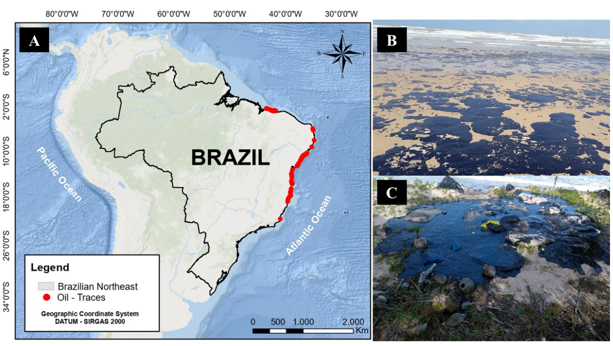

Figure 1. A) Locations affected by the oil spill along the Brazilian coast (updated in 03/19/2020). B) Sergipe state. C) Maraú, Bahia state.

Source: http://www.ibama.gov.br/manchasdeoleo-localidades-atingidas. Examples from Brazilian northeastern sites affected by the oil spill:

Source: http://www.ibama.gov.br/manchasdeoleo-galeria.

The crude oil spilled was formed by a complex chemical mixture of thousands of hydrocarbon-type compounds and small amounts of chelated heavy metals [10]. The origin of the spill itself remains a mystery even two years later! A significant amount of oil has been removed from the beaches, totaling about 5000 tons, in an effort coordinated by state institutions, the Navy and IBAMA (Brazilian Institute of the Environment), but especially pioneered by the civil society volunteers [11]. Apart from the less visible environmental consequences, such as the accumulation of hydrocarbons in the food chain as of January 15, 2020, at least 159 oiled animals had been reported, of which 112 were found dead [12]. In according to [13] the spill probably occurred by buoyancy problems on the tanker losing its cargo. They hypothesis that the leak was caused by tanker buoyancy problems (hull rupture or engine failure) results in leak or dumping of a part of its cargo in the subsurface waters. The estimated volume (5000-12,500 m^3) was similar to what was expected in a continuous leak from an internal compartment tanker with the size between PANAMAX and SUEZMAX.

In addition to immediate and visible consequences, such as habitat pollution and the death of oiled animals, oil spill disasters have multiple short and long-term consequences on entire social and ecological systems that rely on the now contaminated environment. As such, oil spills should be approached in a broad, integrated and multidisciplinary way. Integrated scientific approaches should include disciplines and topics such as oceanography (chemistry, physics, and biology), ecology, spatial modeling, geology, toxicology, epidemiology, microbiology, fisheries, sociology, psychology and economics. If properly implemented, such an approach could provide more effective mitigation pathways and help develop strategies to avoid future disasters, and aid in decision and policymaking [14].

Given the tools and technology available to prevent, deal with and mitigate spills, it is surprising that such a disaster did not merit a transparent cooperative approach in Brazil. The government first ignored the warnings, and then dismissed the criticism regarding its inaction and dismantling of environmental policies, including specific measures to deal with oil spills, and then finally it ideologized the debate. In the end, it acted only when confronted by the Federal Prosecution Service [11], and after the media started registering the risks that marine-dependent people and volunteers were exposing themselves to while cleaning the beaches. Still, the federal measures were limited to cleaning the beaches and releasing insufficient funding for research, which was supplemented by more supportive technical and financial help from the affected states.

Brazil has opted for the easy way out hoping the problem either will disappear on its own or be forgotten as the more visible impacts fade away. This strategy may be facilitated, as the burden of contamination will be heavier on more vulnerable and powerless segments of the population, such as fishers and gleaners. These kinds of articles on the oil spill along the Brazilian coast in 2019 have shown that the response from Brazil's government to this disaster was slow, late, and with flawed remediation plans. Even though some of these important articles report the largest accident, they lack policies and research regarding severity of oil spills, environmental toxicity of the oil, and acute and chronic toxicity to communities (Figure 2). Besides that, the adverse impacts of the oil spill disaster upon Brazil's environment, economy and society were previously described mostly in Portuguese [4,7,15-17] which unfortunately lacks international outreach and visibility. Fewer articles, with more impact [2,4,13,18-22] have brought to attention information on the oil spill along Brazil's northeast and southeast seaboard, trying to find answers and fill data gaps on the geochemistry and identification of the source of the oily material. Discussion about environmental monitoring and response measures that must be implemented to minimize the ecological, economic, and social

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effects of the spill; which is particularly relevant in areas with high tropical biodiversity while experiencing high social inequality, which is presently the case of this northeastern accident in according to [3]. Even more recently, [23] argue that there is still a clear need for coordinated state interventions to mitigation the impacts, considering it's environmental, social, economic, human health and political dimensions even now, two years later. They have conducted focus meeting discussions with fishing communities in Alagoas (one of the most severely impacted states) to assess the local perceptions on the oil spill impacts and they estimate the impact of the oil spill on income generation and food security of coastal communities. The authors also analyzed the government action to handle such impacts and propose a set of recommendations to help alleviate the dramatic effects of this environmental disaster and to prepare for future ones.

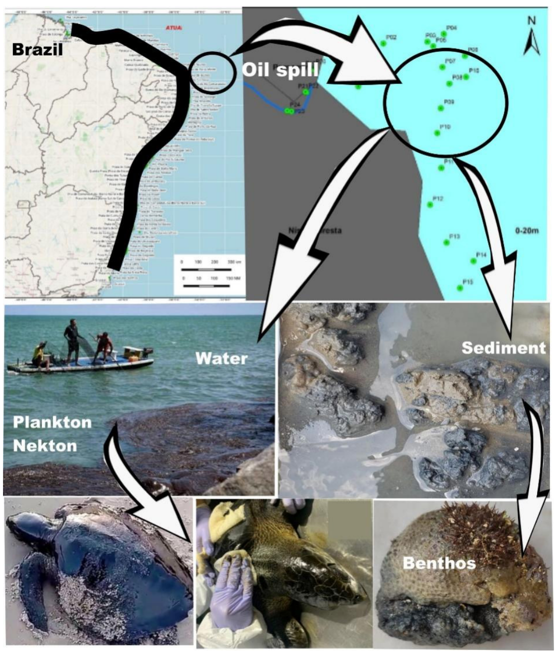

Figure 2. Map showing area of affected area and the acute damages on the Plankton, Nekton, Benthos, water and sediment.

Almost 2 years later now, here we show that basic questions remain unanswered, including the scope of the ecological and social impacts of this spill. It is necessary to understand the dimension of these impacts, how long they are expected to last, anticipate collateral damages, and then propose mitigation options and mechanisms to reduce the magnitude of any future spill. As the oil becomes less and less visible to the naked eye, and the world is ravaged by new disasters (e.g. COVID-19 pandemic), and it is easy to let the largest oil spill in the South Atlantic fall into oblivion, leaving it to nature and for local human communities to bear its consequences for the decades to come.

Our paper deals with a specific site, the "Pirangi Reef area", which was subjected to the oil spill In October 2019, and was previously studied in 2013 and 2014 with no spotting of oil patches in the sediment or in the water [24]. After the oil spill, we sampled new sites to compare and discuss questions on the human-induced changes on the reef system; therefore, water and surface sediments were recovered from areas of small reef patches near tourism boating sites.

2. Background on Oil Impacts over Marine Ecosystems

The release of hydrocarbons from oil spills into marine environments has immediate and acute effects on living organisms. In addition, chronic contamination has an effect over time as hydrogen sulphide, methane and ammonia are released in the environment acidifying the water-sediment interface. Dealing effectively with these impacts includes understanding how pollutants and contaminants in general are released and how they behave in the environment [25]. For example, hydrocarbon petroleum products are quite reactive in aerobic environments via microbial and photochemical reactions [26-29], and the production of hydrogen sulphide (H_2S) is a result of the microbial breakdown of organic materials of crude oil in the absence of oxygen. Hydrogen sulphide is a gas without color, and is flammable, poisonous and corrosive, noticeable by its rotten egg smell and with toxicity similar to carbon monoxide prevents cellular respiration. Monitoring and early detection of H_2S could mean the difference between life and death.

The contamination impact in the medium and long term is a silent one caused by oil being partially degraded and absorbed by the environment. Concentrations of PAHs sufficient to affect individual health following oil spills are common and can remain for long periods in some habitats [30,31]. The polycyclic aromatic hydrocarbons (PAHs) present in oil are immunotoxic to several wild aquatic species. The effects of immune toxicity include damage to the resistance of organisms, making them more subject to new diseases and increased parasitism, delaying population recovery [32], and teleost fish embryo is particularly sensitive to PAHs causing problems related to cardiac development [30].

A significant amount of oil (between 10 to 30%) has been found on the surface of marine substrates, increasing acute epifauna and infauna mortality by contamination and asphyxiation. The organisms that do not die may chronically incorporate the toxic substance in their tissues,

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which then accumulates along the food chain [25]. Another serious consequence of crude oil in the sediment is the acidification and subsequent dissolution of calcium carbonate shells, ranging from microorganisms (foraminifera) to macro organisms (mollusks) as already evidenced by [24].

Studies on the catastrophic Deepwater Horizon (DWH) event in the Gulf of Mexico (GoM), in April 2010, which showed that the composition/accumulation of oil on the seabed was strongly influenced by sediment, texture, composition and sedimentary processes and accumulation rates [14].

It is known that certain types of oil will affect sedimentation in different ways. Heavier and thicker types of oil, which is the type identified in the Brazilian spill, are expected to settle on the substrate. Oil sedimentation may increase if the oil mixes with sand and sinks [25], which is again the case of Brazil's coast where the oil has extensively affected its sand beaches.

A variety of immediately known effects can be identified from organisms directly exposed to oil, such as oil-soaked birds and turtles. Ingestion, direct contact and oiling are part of the immediate threats compromising and affecting animal digestion, and causing eye and nostril irritation, in addition to inhalation of toxic vapors, asphyxiation and suffocation. Particles dispersed in water accumulates in the most sensitive epithelial tissue, such as gills and mucous membranes, obstructing and causing tissue degeneration. Filter feeder animals, such as bivalves, can ingest enough oil to the point of incapacitating their feeding. Other larger benthic animals such as octopuses, lobsters and morays that live in burrows and use them as shelter are most directly affected by the direct oil contact. Organisms with oiled gills are unable to obtain enough body oxygenation and soluble hydrocarbons enters the bloodstream through the respiratory tract. Another effect of oil dispersion into the open sea refers to the influence on plankton surface layers. Plankton is the first element in the food chain, supporting a considerable diversity of marine mammals, fish and invertebrates (Table 1) [12,25,33-36].

Hydrocarbon bioaccumulation is one of the major concerns when an oil spill occurs, but many of the components of oil and petroleum products are biodegradable at some level of the food chain [25] and evidences of the bioaccumulation phenomenon is scarce but can occur [37]. However, it is known that fish are especially sensitive to petrogenic compounds in their early stages of life (cardiotoxicity, phototoxicity), in addition to the carcinogenicity of PAHs and their impacts on the metabolic, immune and reproductive systems [38]. Considering the worldwide scenario of pollutants that are being discarded in the seas, contamination and chemical analysis is mandatory to continue investigations to guarantee the health of ecosystems.

The dimension of the environmental coastal impacts caused by oil spills also depends on the type of coast. The sensitivity of different substrates to oil varies considerably, from rocky shores to gravel beaches, sand, fine sand, mangroves, and coral reefs [25,37]. The oil that hit the Brazilian northeast coast, especially visible on sandy beaches, had an immediate and acute impact on the marine life of the intertidal zone. However, the extent of the coast affected included a great diversity of ecosystems beyond sand beaches, including estuaries, mangroves, reefs, coastal lagoons, riverbanks, etc. The prompt response of volunteers, and later of the government, removed much of the large and more visible patches of oil from the beaches. However, the days and months that followed the peak of the spill were marked by reports of people returning home with their feet stained with oil after walking on apparently clean beaches.

Smaller particles of oil on the sand can reach an extremely diverse benthic community, including mega, macro and half fauna formed by crustacean, Polychaeta, nematodes and mollusks [39,40]. These animals are the also low on the benthic trophic chain and make the link with other environments through feeding various animals in the water column; and the level of contamination in the trophic web needs further investigation.

In addition to the widely affected sandy beaches, the oil reached a range of habitats, from rocky outcrops to some highly vulnerable ones, such as mangroves, estuaries and reefs. These are not homogeneous habitats; they are subject to peculiar local coastal hydrodynamic regimes and present distinctions regarding shape, size and nature of their substrate. Rocky outcrops, for instance, can be severely affected, especially through the accumulation of thick layers of oil on their emerged portions where puddles rich in flora and fauna are formed [25]. Although yet to be fully quantified and assessed, preliminary evidence suggests that the abundant Brazilian northeastern rocky outcrops have undergone a similar oil accumulation process.

Mangroves, in turn, are sheltered ecosystems with low hydrodynamics, a scenario that favors the accumulation of fine sediments retaining contaminants for long periods. They are particularly sensitive to this type of pollution, first because the breathing of their aerial roots can be seriously impaired by a thin oil layer. Secondly, mangroves host numerous permanent and seasonal species. Many of these species, including some of commercial interest to fisheries, use the mangroves as nursery sites, spending sensitive periods of their life cycle there [25,41]. In addition, due to the important connectivity of species in the marine

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Table 1. Possible effects of contamination on marine biota on the coast affected by the South Atlantic oil spill, considering duration of the effect (permanence) due to the gradual transformation and degradation of the oil and occurrence chance.

Effect	Reason	Reason based on local reality	Permanence (Short, medium or long term)	Occurrence chance	Reference supporting the listed effect
Damage or animal death by oiling	Oiling, covering and oil adhesion are very common in birds, turtles and marine mammals. These animals depend on regular contact with the water surface for feeding or surface breathing.	Approximately 130 oiled animals were registered in the first 4 months of the oil's arrival, about 90 sea turtles and 40 birds. There is no previous record of oiled mammals.	Short	***	(Cedre 2007; IBAMA, 2019b; Shigenaka & Milton 2003; Fry & Lowenstine 1985)
Damage or animal death by direct contact with oil particles	Oil particles can accumulate on epithelial tissue on gills, mucous membranes, clogging and damage them. Filter animals such as mollusks can suffer a toxic effect making them incapable of feeding. Organisms with oiled gills cannot accomplish oxygen exchange; soluble hydrocarbons can enter the bloodstream through the respiratory tract. The toxicity can be acute, for example with rapid death of organisms by ingestion. Other effects occur when the organism's survival capacity decreases due to decreased growth and reproduction rate.	The presence of oil was recorded in several filter mollusks such as oysters (*Crassostrea* spp.), in the gills and digestive tract of fishes, legs and mouth area of crabs.	Short, medium and long term	***	(Cedre 2007; IBAMA, 2019b; Viñas *et al*., 2009; Law & Hellou, 1999; Uno *et al*., 2017; Fleeger *et al*., 2003)
Chemical contamination causing malfunction in marine organisms and ecosystem	Polycyclic aromatic hydrocarbons (PAHs) are the most toxic components of oil spills, mainly which are soluble and quickly available for marine organisms. This toxicity is the result of formation of metabolites by organisms which are associated with the DNA resulting in organism malfunctioning. Cardiotoxicity, phototoxicity and carcinogenicity in fish early stages of life	Not recorded. Insufficient research.	Medium and long term	*	Cedre 2007; Jeong *et al*., 2015; Pérez-Cadahía *et al*., 2004; Collier *et al* 2013; Johnston & Roberts, 2009; Johnston *et al*, 2015; Cesar *et al*, 2014; Venturini & Tommasi, 2004; Venturini *et al*, 2008; Camargo *et al.*, 2017.

The occurrence chance is based on the expert opinion of the authors associated with what is known in the literature (* little evidence in the literature; ** some evidence; *** strong evidence). By default, regional impacts are also local, while national impacts are local and regional.

environment, the oil pollution of mangroves can affect ecological productivity in the short, medium and long-term, compromising the biodiversity in general, and in fisheries in particular.

Reef coral ecosystems are protected by mucus secreted by their polyps and can withstand small isolated oil accidents, especially because a protective layer of water usually remains between the corals and the smooth oil surface. However, depending on the type of incident (intensity and repetition) and the polluting agent, these invertebrates can suffocate [25].

Studies that modeled the distribution, destination and effects of oil, associated with toxicity tests of various species, suggested that more thorough conclusions about the damages caused by oil spills to natural resources is only elucidated after several years of monitoring and information [42]. Poor cleaning, negligent monitoring and insufficient research, as Brazil has demonstrated, will not only delay conclusions, but also provide insufficient and inconclusive data. Some effects of contamination on marine biota are shown in Table 1.

3. Socioeconomic Impacts

Oil spills also have significant consequences on human livelihoods, by affecting social, cultural and economic activities (Table 2). Coastal tourism is immediately affected by tourists afraid of possible health effects caused by direct contact with oil [43]. Coastal tourism is one of the main economic activities in the Brazilian tourism sector, given the country's permanent favorable weather, especially in the northeast. According to anecdotic information from the media, hotels and tourist activities were greatly impacted at the peak of the spill when the oil was clearly visible in the sea and on the beaches [44]. As the oil reached the mangroves, aquaculture, especially exotic white shrimp (*Litopenaeus vannamei*), and salt production were affected as well. The northeast is the main exporter of Brazilian shrimp [45] and produces 98% of Brazilian salt [46]. Although it is yet to be quantified, the economic effects on tourist operators, farmers and salt businesses are expected to be less damaged than on artisanal fishermen and their families which are among the most economically vulnerable coastal groups [47]. While larger businesses can possibly endure some level of economic hardship caused by such a disaster, this is often not the case for the local subsistence communities and commercial fisheries that depend on the sea. In the state of Bahia alone, an estimated 43,000 fishermen were affected by the disaster [44].

Fisheries were inevitably affected in Brazil because the risks of contamination directly interfered with the sale of fish, with up to 50% drop in income being mentioned by artisanal fishers [23]. Although part of this loss was due to decreased catches, due to a lower consumer demand, fishermen also lost income due to lower prices enforced by middlemen even in areas not directly affected by the oil spill. Women working in fisheries, as gleaners for example, are especially vulnerable because the types of habitats they tend to use (mangroves and sandbanks) and the animals they tend to exploit (e.g., mollusks) are amongst the most sensitive to oil contamination because they are filters [48]. Thus, a coastal oil disaster may accentuate gender vulnerability in fishing communities. Some eventual government support is likely to benefit only a small portion of fishers as per bureaucratic requirements, such as being registered by the fisheries secretariat, which gives them the right of a fishing license. In some of the northeastern states, about 10% of the artisanal fishers have a fishing license. Even if less bureaucratic means is adopted, such as having the villages and their local fishing associations identify the fishers to be compensated temporarily, this is still unlikely to fix their economic losses. This would be so because the fish from Brazilian artisanal fisheries are part of complex value chains, often with invisible links and no taxes attached [49,50].

Additionally, fishers and their families are subject to different levels of health problems, from those caused by the direct contact with oil to psychological ones related to the socioeconomic uncertainty generated by the spill, such as the perspective of job loss and food insecurity [51]. These effects can last for years and are not usually accounted for by governments in places where oil disasters have happened [52,53].

4. Methodology

Photographs and videos released at the time of the event of the oil spill disaster confirmed by national media, locations where the oil was deposited on the marine substrate. We collected water and sediment samples in Pirangi reef area in Rio Grande do Norte state, once oil was spotted at this site in 2019.

This specific site of Pirangi was studied in 2013 and 2014 with no spotting of oil patches or other forms in the sediment and in the water in according to [24]. After the oil spill, we sampled new sediment sites in October 2019 to compare with the same methodology described in by the abovementioned authors. We intend in this study to discuss questions on the human-induced changes on the reef system, therefore water and surface sediment were recovered by scuba divers from 55 stations at reefs at Pirangi in June 2013 and July 2014 (Figure 3). Samples were recovered from reef areas, sandy sediments, and macroalgae substratum using a small knife. In Pirangi in 2013, Stations 16 to 20, 27, and 28 and Stations 3 to 15 in 2014 were sampled from areas of small reef patches near

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Table 2. Possible socioeconomic and health effects on the coastal human communities affected by the South Atlantic oil spill.

Effect	Reason based on local reality - effect	Scale	Impact	Reason - scale	Reference supporting the listed effect
Reduced fishing catches	Fish and seafood mortality may affect catches	Local	*	Fishers and gleaners are majorly from the small local communities affected. Industrial fisheries are less common in the region and tend to fish offshore areas, which are less likely to have been affected with the same magnitude	(Born et al. 2003)
Reduced fisheries income	Fish and seafood mortality and lower demand may force prices and revenues down. Some middlemen might abuse the vulnerability of coastal fishers	Local	***	The same as above	(Garza-Gil et al. 2006; McCrea-Strub et al. 2011)
Changes in fishing grounds and effort	If closer grounds are contaminated, fishers that have the means may switch grounds, with consequences on effort (e.g.: need to use different gear or spending more fuel to reach further grounds)	Local	**	Fishers in the region tend to fish closer to their homes, especially if they are small-scale	(Born et al. 2003)
Loss of food sovereignty	If fish and seafood are contaminated, coastal communities may need to purchase protein they would otherwise get for cheaper (just at the cost of their work and gear). However, there is a chance they would return to fishing even if still contaminated for not being able to afford purchasing protein	Local	*	Coastal communities are the only ones that rely directly on marine resources	(Jonasson et al. 2019)
Increased food insecurity	The dependency on external markets, conditioned to money payment, may force people to reduce their protein intake. Externally acquired protein may be of lower nutritional quality (e.g., canned meat and highly processed protein). Even if locals resume fishing, their food might not have the same quality due to contamination	Local	**	Same as above	(Osuagwu and Olaifa 2018)
Contamination from ingesting seafood	Heavy metals (cadmium, mercury and lead) from the spill can accumulate in the food chain, potentially causing neurological and reproductive damages, and even cancer. In the absence of affordable alternatives, locals may keep ingesting contaminated seafood	Regional	***	Especially important for the locals, but the fish sourced locally can be sold in the state markets	(Solomon and Janssen 2010)
Contamination from direct contact with oil	Removal of oil using makeshift gear (or no gear) expose people to defatting (resulting in dermatitis and skin infection), and temporary eye, nose, or throat irritation, nausea, or headaches. Those exposed for longer can have DNA damage	Regional	**	In addition to local volunteers, people from the region (and elsewhere) travelled to the contaminated sites to help with the clean up	(Solomon and Janssen 2010)
Increased rates of psychological problems	Increased rates of unemployment, reduced income and lack of clean (and free food) can increase the rates of depression, anxiety, post-traumatic stress disorder, and psychological stress	Local	**	Effect limited to those directly affected	(Solomon and Janssen 2010)

Effect	Reason based on local reality - effect	Scale	Impact	Reason - scale	Reference supporting the listed effect
Loss of cultural services, such as destruction of historically used grounds for work or leisure	Coastal communities rely on coastal habitats for their wellbeing and traditions.	Local	*	Coastal cultural ecosystem services associated to fisheries are locally dependent	(Outeiro et al. 2019)
Shrimp farming	This activity is developed in the mangrove, supposed to be one of the environments most affected by the spill	National		The region is the main national producer and international exporter of shrimp in Brazil	(Duke 2016)
Algae aquaculture	Practiced in banks very close to the shore, this activity is likely to have been widely affected by the spill			Agar-producing algae are exported to the remaining states	(Yang et al. 2020)
Community-based tourism		Local	*	Although more of an informal activity, it is relevant for some traditional communities as a source of income	(Bordelon et al. 2015)
Coastal tourism	Vacancy rate may increase soon after a disaster as tourists are afraid of contamination or fear that the site has lost its landscape attractions (e.g., clear water and white sand beaches)	Regional	*	Decreased taxes will particularly affect the states that have a strong reliance on tourism, but the impacts are expected to last while they are visually perceived	(Price-Howard and Holladay 2014)
Increased in gender inequality	Mangroves and sand banks, which are among the most affected areas, are especially harvested by female gleaners. Men often fish offshore, where some of them can target unaffected stocks	Local	**	Women in fishing communities are expected to being affected by the spill	(Defiesta and Badayos-Jover 2014)

The intensity of the effect is based on the authors' expert opinion associated to what is known in the literature (*little evidence in the literature; **some evidence; ***strong evidence). Impacts that are regional are by default also local, while those that are national, are also local and regional.

tourism boating sites. Each area was sampled twice, but exact station locations differed from 2013 to 2014.

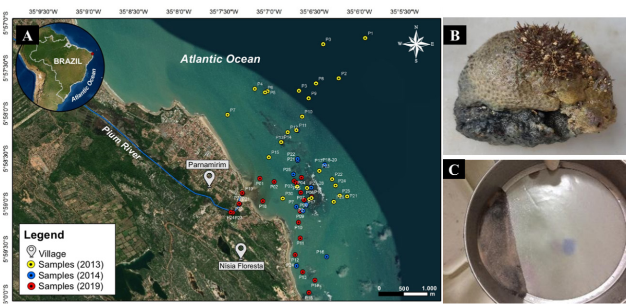

Figure 3. A) Random sampling points of the sediment collection carried out in June 2013, July 2014 (no oil spotting), and October/2019 (with 95% of samples containing oil). B) Portion of reef substrate with oil crude collected in Pirangi (RN). C) Sediment in a sieve showing oil pollution.

In October of 2019, after the oil spill, we focused on the Pium river area and sampled 15 more sediment, reefs and microalgae, and water samples to observe the presence of oil. Processing of marine sediments followed standard procedures from [24,54] where a fixed volume of 50 cm^3 of sediment was washed over a 63 μm sieve to retire silt and clay and spot oil in analyzed sediment.

5. Results

Along the entire northeastern coast, considerable particles and portions of oil were buried in the sand and in organisms mainly due to the movements of coastal hydrodynamics. Sampling done in October 2019 in the same area previously sampled in 2013 and 2014 shows that more than 95% of the unconsolidated sediment samples, including some corals, had some evidence of oil (Figure 3). This is a striking contrast with samples done in the same region with the same methodology in two previous consecutive years (2013 and 2014), which showed no evidence of oil on the seabed and was evidenced by [4]. Figure 3 shows maps from 2013 and 2014 published data and no mention of oil in the sediment study; and samples collected in 2019 (Figure 4) with oil evidences on 95% of samples.

Oil mixed with sand has been found from a few centimeters to almost 10 cm deep into the sediment in beaches, and also buried in water depths between 3 and 12 m in some of the local reefs and estuaries. River Pium's estuary and the reefs of Pirangi do Sul, indicates that the scope of

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the contamination is far beyond what was previously assumed. Thus, there is a considerable range of threats and impacts on the marine biota, many of which are yet to be assessed on the Brazilian coast, especially given that the area affected is on a continental scale (about 2500 km). To date, the magnitude of the event is given by the oil that has been removed in the form of stains or fragments on the surface of beaches.

Figure 4. The official map with damaged sites by IBAMA, which the site of Pirangi and Pium River are not included. They were however severely affected by the oil accident event in 2019.

6. Discussion

Almost twenty months after the first signs of the spill, governmental investigations are yet to clarify crucial points such as the origin, extent and cause of the spill, and specific characteristics of the oil, which seriously compromised immediate and posterior actions.

Still no estimate of the amount of oil that remains on marine sediments, estuaries or mangroves, or the amount that has infiltrated into the Brazilian sand beaches, and the magnitude of an oil accident cannot be measured by the amount of oil that has been removed and sighted on beaches and coastal areas.

As an example, Brazilian tropical reef ecosystems are not, in general, built by corals, but by a rich diversity of species that vary according to the region [55]. This peculiar formation of Brazilian reefs prevents comparisons with previous oil spills in different reefs of the world when mucus secreted by the polyps of the corals could withstand isolated oil accidents [25]. Thus, it is reasonable to assume that the living surface of these ecosystems may be impacted in the medium and long term, and thus chemical contamination on the reefs of the affected area must be investigated in detail considering their ecological and socioeconomic importance. This indicates that the scope of the contamination continues its reach far beyond what was previously assumed since the Brazilian coastal area affected is very large on a continental scale.

6.1 Political Scenario

In the event of a major oil disaster, such as this one we are reporting, immediate containment and waste removal should happen, but not as isolated actions: they should be accompanied by the application of robust and effective strategies including waste containment, cleaning and removal protocols. The federal government took more than 40 days to adopt the Contingency Plan for Oil Pollution Incidents (PNC from Portuguese) previously in place since 2013, and they only implemented the Contingency Plan after being confronted by the Federal Prosecution Service twice [11]. Part of this inaction was due to a systematic dismantlement and clearing of the Brazilian environmental programs, especially during 2019 [56]. In April 2019, less than four months before the oil spill, the federal government extinguished several councils, committees, commissions and collegiate bodies associated with the federal public administration (Decree 9,759 / 2019). This included two committees that were part of the PNC, explaining why it took so long for it to be implemented. A timely implementation of the PNC would have decreased the damage extension, instead, the official government response in the acute period of contamination was groundless propagandized ideological accusations (against Venezuela, for example) or, when these smoke screens did not work, the public got the silent treatment. Little information was disclosed other than the locations on a map affected by the oil spill along the Brazilian coast (updated in 03/19/2020) by federal agency IBAMA, the Brazilian Institute of Environmental and Renewable Natural Resources. After spotting oil in the water, a specific scientific mission was performed to evaluate the water and sediments situation in Pirangi do Sul . We have observed extensive areas where oil spillage has acutely damaged the ecosystem as a whole. This coral reef has been evaluated since 2013 [24,54,57,58] with no mention of oil in this specific site, until 2019 when we verified that it was impacted by this oil accident. We have then added a new information on the IBAMA original map as it follows in Figure 3 that includes the present site of Pirangi and Pium River as severely affected by the oil accident event in 2019 as we have shown in this article.

Under pressure by public opinion, in December 2019, the government published a timid research call of about $320,000 US (maximum of US $25,000.00 per project), being a negligible amount to properly investigate the extension of the damage caused by the oil spill accident. And in the same period, MCTI through "Ciências do Mar", a program with actions forecasting 2019 to 2030 with the objective of managing knowledge for the conservation and sustainable use of the sea, launched an emergency action with the financing of approximately $1.4 million US for research groups already established (INCTs and PELDs) to develop research for impact by oil spills.

Some state governments, on the other hand, although insufficient, have been more proactive and provided more amounts of funding. State initiatives have also counted on partnerships and collaborations with public and private research institutions, associations, universities and non-profit organizations.

While the origin of the oil remains a mystery, and any scientific effort to clarify that should have been welcome, the scientific community in Brazil has been subject to a smear campaign to discredit its findings and opinions. This is especially strong when academics denounce attacks on the environment and/or human rights, which make the topic of an oil spill especially delicate, as it touches on both issues [59].

So far, and despite the length of time passed, none of the hypotheses on the origin of the spill has been confirmed due to lack of scientific consistency. Perhaps not surprisingly, many of these hypotheses have been aired first by the government, which has been effective in pointing fingers, but far less efficient in providing reliable and robust information. For example, the oil has been suggested to leak from: 1) oil tankers in waters beyond 200 nautical miles from Brazil, 2) cleaning of a vessel, 3) sinking of a foreign vessel with hull drilling and continued oil leakage, and 4) continued leakage from the national oil exploited in the pre-salt layer. However, we still have no concluding remarks.

6.2 Future Directions

Oil production, transportation and consumption continue to carry risks in the 21st century, which makes it necessary to think about the adoption of new policies that encourage cleaner and safer production associated with ambitious preventive and mitigation disaster plans. When disasters happen, they should teach us lessons on how to avoid them and how to make sure that the most vulnerable, in nature and in society, will not be the ones paying the highest price. It is a societal duty, including academia and government, to ensure these disasters are properly investigated and the consequences accounted for, even when media interest refocuses public attention. These types of efforts require working in partnership, where the scientific community is not to blame for societal problems, but rather as a door to alternatives for this disaster and prevention of future environmental problems Brazil and the rest of the world may face.

A new disaster, even of a global magnitude, such as the ongoing pandemic (COVID-19), should not be a reason or distraction to forget about previous disasters, especially in places where poorer human communities suffer the highest losses. The unavailability of transparent results hinders actions focused on solving the problem.

This impact scenario, as witnessed, still has potential damages not yet measured or mitigated, leading us to a series of important considerations in order to have a less compromising future situation that is aggravated in countries of large territorial extension and high social inequality, such as Brazil.

It is essential and basic to have operating government protocols in place for immediate actions for oil removal, compensation for socioeconomic losses, assessments of the level of contamination in habitats, organisms and human beings. In addition to urgent measures, habitat recovery and monitoring of the level of contaminants must be used in order to guarantee the health of the environment. Integrating the various scientific areas of knowledge is essential for a holistic approach on this broad topic. For example, to understand the sum of stressors in reef environments, such as we are currently facing with warming waters and coral bleaching in tropical reefs off the Brazilian coast.

However, it is no longer possible to hide the urgent need for a change in actions in the face of the use of natural resources and oil exploration. The behavioral distortions in consonant with unrestrained consumption typical of societies that aim at high productivity, lead us to environmental catastrophes, scarcity, and contamination of our own resources. We have already opened our eyes and see the problems, now we need to make the necessary changes. In the absence of monitoring, this type of impact remains unrelated to past oil spill events, preventing further protective and mitigation measures for future disasters. A strategy for mapping impact on benthic habitats also needs to be addressed and discussed to increase better responses.

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REVIEW

Knowledge and Opportunities from the Plastisphere: A Prelude for the Search of Plastic Degrading Bacteria on Coastal Environments

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ABSTRACT

Plastic pollution has become an urgent issue, since its invasion to every ecosystem has led to multiple impacts on the environment and human populations. Certain microbial strains and genera had shown the ability to biodegrade plastic sources under laboratory conditions. In this minireview, we collect and analyze scientific papers and reports of this microbial activity as we contextualize this information on the global plastic pollution problem, to provide an updated state of the art of plastic biodegradation with microbial agents. Along with a broad understanding of the general process of plastic biodegradation hosted by microorganisms. The contributions of this minireview come from the identification of research gaps, as well as proposals for new approaches. One of the main proposals focuses on coastal environments and in particular coastal wetlands as a great microbiome source with potential for plastic biodegradation, whether reported or undiscovered. Our final proposal consists of the application of this knowledge into technologic tools and strategies that have a remarkable impact on the battle against the plastic pollution problem.

1. Introduction

The plastic pollution problem

Plastics are synthetic or semi-synthetic polymers mainly produced from petrochemicals, characterized by their high resistance/density relationship, their great thermal and electric isolation properties, as well as resistance to acids, alkalis and solvents [1]. These materials have applications in multiple industries and business sectors like trading, packing, building materials, medical and pharmaceutical uses, automotive industry, home appliances, agriculture and many mass production products for the everyday human consumption [2,3].

These polymers pollute and invade a lot of environments due to the single-use and improper waste management. The main plastic types considered environmental pollutants are High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polyvinyl Chloride (PVC), Polystyrene (PS), Polypropylene (PP), Polyester (PES), Polyamide (PA) and Polyethylene terephthalate (PET) [4].

Plastic pollution has become one of the biggest environmental threats by invading every ecosystem. It has been reported the presence of plastic debris (microplastics)

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from deep-sea sediments [5], to the highest areas of the mount Everest [6]. The presence of microplastics in the human placenta has been documented as well [7].

Around 13 million tons of plastic have been thrown to oceans annually, besides the global annual production of 300 million tons of plastic debris [8]. In México, nearly 83,343 tons of trash are collected daily [9] and in the municipal solid waste composition, plastic spans 10.9% [10].

Main consequences of this pollutant relay on contamination of water sources like rivers, lakes or oceans leading to the formation of continental sized trash patches in the middle of the Pacific Ocean [11]. Also, additives and other compounds present in plastics impact on coastal, marine and inland soils, damaging their physicochemical properties and fertility [12].

Biotic impacts come from mutilation, intoxication and asphyxia of marine, coastal and terrestrial organisms [13]. Human population affectations include the intake of microplastic polluted food [14] to neurotoxic damage from PAH´s, Phthalates and PCB´s [15]. Furthermore, plastic residues represent public health and economic hazards to human communities.

2. Coastal Wetland Ecosystem Goods and Services

Worldwide ecosystems shelter goods and services that provide human populations resources for their basic needs; these so-called ecosystem services and natural capital [16] are in decay because of environmental issues such as plastic contamination. This situation is a threat to global human economics and welfare, ever since biodiversity is linked in so many complex ways to ecosystem functionalities and their output ecosystem services [17].

Particularly, coastal wetlands provide human population wide and diverse goods and services due to the enormous biodiversity within these ecosystems. Some of these goods and services are categorized as ecosystem services framework [18]. Supporting ecosystem services include the primary production of microbiotic (bacteria, fungi, protozoea) and macrobiotic (migratory birds and commercial interest fish and crustaceans) life forms, soil formation and enrichment. Provisioning goods and services are represented by sources like fresh water, seafood, honey and woods. Regulating functions such as climate regulation by carbon dioxide sequestration and flood and storms mitigation. The Cultural category is covered as aesthetics, recreational, educative and spiritual values for native human population as well as foreign people through ecotourism [19].

3. Microbial Biodegradation of Plastics

Environmental plastic pollution solutions have become an urgent subject and an interesting approach could be just below ourselves. Diverse microbes have shown the ability to degrade plastics; particularly bacterial strains isolated from different environments that have been studied and reported in diverse scientific publications. Some of these papers are reviewed in the present study.

Bacteria have been widely researched in plastic biodegradation matter, since they are easy for cultivation and isolation, and the facility for bioprospecting metabolic pathways, ecological functions and subproduct related information through metagenomic analysis and sequencing of the 16S ribosomal gene [20,21]. In this review, scientific evidence of plastic biodegradation hosted by bacteria dates from at least 1991 [22,23]. In general, research has focused on confirming and assessing plastic degradation by bacteria either through in vitro or in situ assays.

Depolymerization activity is usually measured with diverse methodology such as visual assessment through detecting roughening, cracking and biofilm formation [24], clear-zone tests [25], weight loss estimates in microbial exposure [26], respiratory activity evaluation such as CO_2 production or O_2 consumption [27]. As well as detection of the activity of specific enzymes or byproducts of depolymerization activity [28,29].

4. Bacterial Biodegradation State of the Art

In the present review, we summarize some bacterial strains and species that have the ability to biodegrade plastic, with complementary information about the habitat of the bacteria, type of plastic degraded, byproducts, enzyme and the bibliographic reference to the paper. This information is categorized and divided based on the type of environment where the bacteria were isolated.

Table 1 shows previous scientific research results from bacteria isolated from anthropic environments, such as municipal waste disposal sites, sewage water, industrial activated sludges or purchased pre-cultured strains from laboratories and microbial strains collections.

Aquatic environment native bacteria are represented in Table 2. Aquatic environments that hold bacterial sources are wide and diverse and some of the most studied environments are sea water and soil, abyssal water and soil, freshwater like rivers and lakes. Some of the least studied are coastal soil and water, highlighting coastal wetland ecosystems.

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Table 1. Municipal waste disposal sites/Other Human environments

ID	Habitat	Plastic type degraded	Degradation by-products	Enzyme	Reference
Pseudomonas, Penicillium, Rhodotorula, Hyalodendron	Landfill	Low Density Polyethylene (LDPE), Polyurethane (PU), Polyvinyl chloride (PVC) Polyethylene glycol	—	Alcano monoxigenase, same as found on hydrocarbon biodegradation (Seneviratne, 2006)	[26]
Ideonella sakaiensis	Sediment from PET-recycling site.	Polyethylene terephthalate (PET)	Terephthalic acid (TPA) & ethylene glycol (EG)	Mono(2-hydroxyethyl) (MHET) terephthalic acid	[30]
Pseudomonas	Final waste deposition site	Low Density Polyethylene (LDPE)	—	—	[31]
Pseudomonas MYK1 and *Bacillus MYK2*	Digester sewage sludge	Polylactic Acid (PLA)	CO_2 and CH_4	—	[27]
Comamonas acidovorans	City soil samples	Polyester-type polyurethanes	Adipic acid and diethylene glycol	—	[32]
Pseudomonas aeruginosa	Previously isolated microorganisms (Microteca/microlibrary)	PET, PU, PP, ABS, HDPE, PVC, ABS, PS	—	—	[24]
Acidovorax delafieldii	City soil samples	Poly(tetramethylene succinate)-co-(tetramethylene adipate) (PBSA)	—	Lipase	[33]
Bacillus subtilis, Bacillus cereus, Bacillus lentus, Pseudomonas aeruginosa, Staphylococcus aureus, Klebsiella pneumoniae, Streptococcus pyogenes, Escherichia coli, Proteus vulgaris, Micrococcus.	FADAMA soil	Polythene plastic bags and environmental plastic materials	—	Polyurethanases (Koutny et al., 2006).	[34]
Brevibacillus borstelensis	Soil from Polyethylene waste deposition site	Branched low-density polyethylene	—	—	[35]
Rhodococcus ruber	Sediments with polyethylene debris from agriculture use	Polyethylene	—	Esterases	[36]
Streptomyces viridosporus, Streptomyces badius and *Streptomyces setonii*	Enzymes from cultured *S. viridosporus*, *S badius* and *S setonii*	Starch-polyethylene degradable plastic films	Primary and secondary alcohols	—	[23]
Pseudomonas putida (AJ) and *Ochrobactrum* (TD)	Dangerous waste disposal site	Vinyl Chloride	—	—	[37]
Pseudomonas fluorescens	Naval Research Laboratory, Wahington D.C.	Polyester polyurethane	—	Enzyme with protease activity	[38]
Thermomonospora fusca	Compost from green waste	Aliphatic-Aromatic Copolyesters (synthesized from 1,4-butanediol, adipic acid, and terephthalic acid (BTA))	—	—	[39]
Schlegelella thermodepolymerans and *Pseudomonas indica* (K2)	Activated sludge	Poly(3-hydroxybutyrate-co-3-mercaptopropionate). [poly(3HB-co-3MP)]	3HB Oligomer linked as thioester	Poly(3-hydroxybutyrate)(3HB) depolymerase	[40]

ID	Habitat	Plastic type degraded	Degradation by-products	Enzyme	Reference
Clostridium botulinum and *Clostridium acetobutylicum*	Sewage slugde and methane sludge	Poly(b-hydroxybutyrate) (PHB), poly(b-hydroxybutyrate-co-11.6%-b-hydroxyvalerate) (PHBV) and the synthetic polyester poly(o-caprolactone) (PCL)	—	PCL depolymerizing	[25]
Bacillus amylolyticus, Bacillus firmus, Bacillus subtilis, Pseudomonas putida, Pseudomonas fluorescens	Municipal solid waste from compost plant	Polyethylene bags	—	—	[41]
Bacillus cereus, B. megaterium, B. subtilis, Brevibacillus borstelensis	Culture fields	Polyethylene	Hydrocarbons (saturated and unsaturated) and alcohols of higher molecular weight	—	[42]
Rhodococcus rhodoshrous	Purchased isolates from American Type Culture Collection	High density polyethylene (HDPE), Low density polyethylene (LDPE) and Linear low-density polyethylene (LLDPE) films with balanced content of antioxidants and pro-oxidants (manganese+iron or manganese+iron+cobalt)	—	—	[43]
Actinomadura sp. S14, *Actinomadura sp*. TF1, *Streptomyces sp*. APL3 y *Laceyella* sp. TP4	Compost soil	Polyester biodegradable plastics; polylactic acid (PLA), polycaprolactone (PCL), poly-(butylene succinate) (PBS) & polybutylene succinate-co-adipate (PBSA)	—	S14, TF1 & TP4 produced PLA and PBSA depolymerase (50°C), APL3 (40°C). Actinomadura sp. S14 (PCL depolymerase) Actinomadura sp.TF1 (PLA depolymerase), Streptomyces sp. APL3 (PBS depolymerase), Laceyella sp.TP4 (PBSA depolymerase)	[44]
Paenibacillus amylolyticus TB-13 *(Bacillus amylolyticus)*	Sediment samples from multiple sites	Poly(lactic acid), poly(butylene succinate), poly(butylene succinateco-adipate), poly(caprolactone) and poly(ethylene succinate)	—	Proteases and esterases	[45]
Streptomyces sp. AF-111	Sewage sludge from Treatment Plant Rawalpindi Pakistan	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV)	—	PHBV Depolymerase	[28]
Bacillus sp. AF8, *Pseudomonas sp* AF9, *Micrococcus sp*. 10, *Arthrobacter sp*. AF11, and *Corynebacterium sp*. AF12	Soil from plastic deposition sites	Poly [4,4'-methylenebis (phenyl isocyanate)-alt-1,4-butanediol/poly (butylene adipate)] (Polyurethane, PU)	p-nitrophenol (Spectroscopy), CO_2 (Sturm test)	Esterase Polyurethanases (plate assay with Coomassie blue R 250).	[29]
PN24 *Bacillus cereus*, PN12 *Bacillus pumilus*, LNR3 *Arthrobacter.*	Waste deposition sites and artificially developed soil beds containing maleic anhydride glucose, and small pieces of polyethylene.	High and low-density polyethylenes (HDPE/ LDPE)	—	—	[46]

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Table 2. Marine, Freshwater and coastal environments

ID	Habitat	Plastic type degraded	Degradation by-products	Enzyme	Reference
Pseudomonas, Staphyloccoccus, Moraxella, Micrococcus, Streptococcus	Mangrove soil	Polyethylene bags and plastic cups	—	—	[47]
Pseudomonas (*Pseudomonas stutzeri*)	River water	High molecular weight Polyethylene Glycols (PEG´s)	Glyoxylic acid	PEG dehydrogenase (Single polypeptide)	[22]
Rhodobacteraceae, Rhodospirillaceae, Oceanospirillaceae, Glaciecola	Seawater	Poly(3-hydroxybutyrate-co-3hydroxyhexanoate) (PHBH)	—	—	[48]
Shenawella (CT01), *Moritella* (CT12, JT01, JT04), *Psychrobacter* (JT05) and *Pseudomonas* (JT08)	Marine dephts soil	Poly ε-caprolactone (PCL), aliphatic polyesters	—	—	[49]
Terrabacter tumescens, Terracoccus luteus, Brevibacillus reuszeri, Agrobacterium tumefaciens, Burkholderia vietnamiensis, Duganella zoogloeoides, Pseudomonas lemoignei, Ralstonia eutropha, Ralstonia pickettii, Matsuebacter chitosanotabidus, Roseateles depolymerans, Rhodoferax fermentans, Variovorax paradoxus, Serratia marcescens, Acinetobacter calcoaceticus, Acinetobacter junii, Pseudomonas pavonaceae, Pseudomonas rhodesiae, Pseudomonas amygdali, Pseudomonas veronii	Soil samples (ando-soil, woody area at Shima-Tsakuba, brown lowlands soils, sandy riverside soil and riverside mud)	Poly(β-hydroxyalkanoate), poly(ε-caprolactone), poly(hexamethylene carbonate), or poly(tetramethylene succinate)	—	—	[50]
Bacillus mojavensis TH309	Bio-deteriorated plastic waste from Tidal zone on Carsamba coast of Samsun	Poly(e-caprolactone) (PCL)	—	Esterase (BmEST)	[51]
Alcalinovorax, Hyphomonas and *Cycloclasticus.*	Seawater and soil samples	Poly(ethylene terephthalate) (PET) & Biodegradable Plastic bags (BD)	Insoluble by-products of the hydrolytic degradation of PET.	Esterase	[52]
Pseudomonas pachastrellae JCM12285	Marine plastic debris in coastal seawater	Poly(ε-caprolactone) (PCL)	—	PCL hydrolase	[53]
Gammaproteobacteria, Alphaproteobacteria, and Flavobacteria (Class level)	Microplastics exposed to seawater from coastal zones	Polypropylene (PP) and polyvinyl chloride (PVC) microplastics	—	—	[54]
Arcobacter and *Colwellia*	Three types of coastal marine sediment from Spurn Point, Humber Estuary, U.K.	Low Density Polyethylene (LDPE) microplastics	—	—	[55]
Bacillus cereus and *Bacillus gottheilii*	Sediments from Matang mangrove in Perak	Polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), and polystyrene (PS)	—	—	[56]
Lysinibacillus fusiformis strain VASB14/WL and *Bacillus cereus* strain VASB1/TS	Rhizosphere samples from mangrove (*Aviccenia marina*) soil	Polythene	—	—	[57]

Microbial research has focused on new sources. One of the most popular in recent years is the gut microbiome from organisms such as Coleoptera, Lepidoptera, Lumbricidae and certain mollusks. Some organisms contain bacterial strains capable of degrading complex chemical structured materials such as wax or wood timbers. Assays on these organisms and their gut microbiota have shown a certain capacity of degrading plastic samples as well (Table 3). These host organisms could also be referred to as holobionts [58].

5. General Process of Biodegradation by Microorganisms

For a better comprehension of the topic, a deeper understanding of the biodegradation process is required. Thus this metabolic mechanism is the core of the activity and eventual application of plastic degradation through bacterial strains.

The biodegradation process may differ depending on the genera and species, but the main process is illustrated in Figure 1 and described as follows:

The general microbial biodegradation process can be described in three stages: Biodeterioration, biofragmentation and assimilation [66]. At the time environmental abiotic degradation occurs vias Mechanical, Chemical, Photocatalytic Thermal and Ozone-induced degradation [67].

Biodeterioration

It all begins when the plastic material is exposed to the environment (where abiotic degradation factors join the process), then, bacteria start to settle down into the plastic surface to form a biofilm or the so called "Plastisphere" [68]. Microbial activity of consortia (i.e. protein and enzymatic activity) causes deterioration of physical, mechanical and chemical properties of the polymer, leading to cracking of surfaces, formation of oligomers, monomers, as well as

Table 3. Macrofauna gut microbiome (Holobionts)

ID	Habitat	Plastic type degraded	Degradation by-products	Enzyme	Reference
Escherichia, *Shigella, Asaia* and *Acinetobacter,Rhodocytophaga, Bergeyella*, *Diaphorobacter, Hydrogenophaga, Zhizhongheella*.	Gut microbiome from *Galleria mellonella*	Low-density polyethylene (LDPE)	Glycol	—	[59]
Enterobacteriaceae, Spiroplasmataceae, and Enterococcaceae	Gut microbes from *T. obscurus* and *T. molitor* (purchased from insect breeding plants)	Polystyrene (PS)	—	—	[60]
Dyella, Lysobacter, and *Leptothrix*	Microbes from larvae *T. molitor* gut. larvae purchased from market	Polystyrene (PS) and Low-density polyethylene (LDPE) Foams	—	—	[61]
Family Enterobacteriaceae, Sphingobacteriaceae, and Aeromonadaceae	Microbiome gut from Soil Snail *A. fulica* purchased from Jiaxing Hong-Fu Breeding farm (Zhejiang, China),	Expanded polystyrene (PS) foam	—	—	[62]
Serratia sp. strain WSW	Microflora from *P. davidis* larvae gut	Polystyrene (PS) Styrofoam	—	—	[63]
Actinobacteria (*Microbacterium awajiense, Rhodococcus jostii, Mycobacterium vanbaalenii* and *Streptomyces fulvissimus*) and Firmicutes (*Bacillus simplex* and *Bacillus sp.*)	Earthworm´s gut	LDPE	Volatile compounds (octadecane, eicosane, docosane and tricosane) and nanoplastics		[64]
Bacillus and *Serratia*	Microbial gut from *G. mellonella L.* larvae purchased from Huiyude Co.	Polyethylene (PE) and polystyrene (PS)	Long chain fatty acids as the metabolic intermediates of plastics in the residual polymers	—	[65]

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carbon and nitrogen sources [66].

Biofragmentation

In order to reach polymer assimilation, microorganisms have to break polymer bonds for cellular absorption of oligomers and monomers, since polymer chemical structure is too big and complex to be directly absorbed by microorganisms [69]. This goal is reached through the secretion of polymer-specific enzymes and free radical generation [66]. Action of extracellular enzymes on a polymer is generally defined as the concept of depolymerization [70]. Biofragmentation could lead to microplastic formation if the plastic media is not assimilated yet by microorganisms [64].

Assimilation

This stage is defined for the real absorption of the plastic atoms into the microbial cell; providing essential needs such as energy, electrons and elementary sources like carbon, nitrogen and phosphorus. Microorganisms are able to sustain and reproduce at the time they produce energy via aerobic respiration, anaerobic respiration or fermentation [66].

As a result of polymer cleavage, monomer/oligomer absorption and metabolic processation; microbes can release mineral molecules, contributing to natural biogeochemical processes, as well as organic molecules, which some could be ecotoxic threats under certain conditions and degrees [66]. Mineralization differs by the presence of carbon dioxide and water under aerobic conditions, and methane and carbon dioxide for anaerobic [67].

Some byproducts laid by microbial metabolic activity through the biodegradation process could have potential use for other technological or industrial uses and applications [71].

The chemical reactions resulting from plastic biodegradation through aerobic and anaerobic respiration are illustrated by Equation 1 and Equation 2.

$$C\ plastic + O_2 \rightarrow CO_2 + H_2O + C\ residual + Biomass$$

Equation 1. Aerobic microbial biodegradation of plastic [72].

$$C\ plastic \rightarrow CH_4 + CO_2 + H_2O + C\ residual + Biomass$$

Equation 2. Anaerobic microbial biodegradation of plastic [72].

Aerobic microbial biodegradation of plastics (Equation 1) is performed by the use of oxygen as electron acceptor, breaking down organic chemicals into smaller organic compounds or monomers. Carbon dioxide and water are excreted as byproducts of the cleavage. Meanwhile, in anaerobic microbial biodegradation (Equation 2), microbes set nitrate, sulphate, iron, manganese and carbon dioxide as electron acceptors due to lack of oxygen for the cleavage and formation of smaller compounds [72].

All these stages of the general biodegradation process of plastic through microbial activity are illustrated in Figure 1.

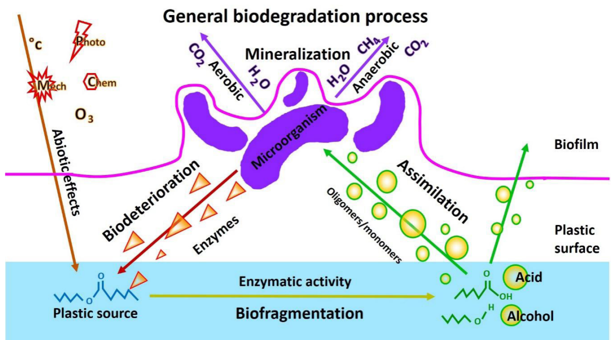

Figure 1. General biodegradation process by microorganisms. The three stages of biodeterioration are illustrated as detailed previously in this review. Note that the Chem, Mech, Photo, °C and O_3 symbols represent Chemical degradation, Mechanical degradation, photodegradation, temperature and Ozone, as they are abiotic drivers for plastic degradation on the environment.

6. Conclusions

Some remarkable features about the state of the art is that bacterial strains come mostly from the bias to the human environment, rather than natural ecosystems. Waste and trash disposal sites, recycling sites, city soil samples and laboratory or purchased strains are the most common origins for plastic degrading bacteria. Otherwise, if natural environments are also well covered, most research papers focus on marine environments, mainly in seawater exposure experiments, leaving a great research gap and an opportunity for studies on coastal and wetland environments, considering that these ecosystems have great biodiversity.

Microbial biodegradation of plastic is known to be an environmentally friendly, cheap and acceptable way for plastic waste treatment [29], so waste management actions should pay some attention to these potential opportunities.

This knowledge could be applied into technological developments for bioremediation or biomitigation of plastic polluted ecosystems. As well as integrate to municipal waste management plans, which even today are not well designed nor applied to most urban and rural locations.

Incursions into new strategies and solutions to plastic pollution will cause positive impacts on the world's ecosystems and human population, with the participation of every government level, as well as corporations and non-governmental organizations. Some other positive impacts of development and action on this subject rely on the achievement of United Nation´s 2030 Sustainable Development Goals. In such objectives as Good Health and well-being, clean water and sanitation, climate action, life below water, life on land and partnerships for the goals. Industrial companies could benefit from economic incentives, positive publicity and product mark-up as a result of extending their value chain responsibility by contributing into plastic-pollution mitigation initiatives.

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Conflict of Interest

The authors have no conflict of interest to declare.

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ARTICLE

Present Status of Aquatic Resource and Its Catch of Mogra River in Bangladesh

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ABSTRACT

Bangladesh is very rich in aquatic fauna with a biodiversity. The present study, conducted during 2015 to 2019, recorded a total number of 131 species (104 fish, 09 prawn, 01 snail, 04 crabs, and 13 turtles) belonging to 26 families were identified from the Mogra River and its flood plain. About ten types of fishing gears, different crafts, hook and line were found operative in the river. Increasing rates of using current jal (16.0-26.40%) and Kapuri jal (11.0-16.70%) were identified as detrimental gears destroying different species. The fish productivity was decreased dramatically from 170.63±10.81mt to 134.75±8.02 mt with a decreasing percentage of 6.26 to 21.03% within five years. Three important aquatic species turtiles (Cyclemys oldhami, Melanocheelys trjuuga and Morenia petersi) became rare and 17 commercially important aquatic species were at the edge of extinction (critically endangered, CR). From the study, 67 species were recorded in the endangered (EN) category, 20 species vulnerable status (VU), 11 species lower risk (LR), 07 species Least concern (LC) and 04 Data deficient (DF). To save the existing aquatic species in the studied riverine ecosystem and ensure better livelihood of the fishes, a team of local management committee, similar to the Hilsa fisheries management technology is needed.

1. Introduction

River ecosystems and biodiversity help in maintaining the ecological balance of the waterbody. There is a necessity of ecological balance for widespread biodiversity and the ecological balance is an indispensable need for human survival [1]. The biodiversity conservation and environmental ethics both are required for sustainable development and survival of aquatic flora and fauna because biodiversity is the foundation of human life [2].

Biodiversity has become a major concern to the fisheries biologists against the backdrop of rapid decline in the natural population of fish and aquatic biota across all the continents of the world. Biodiversity encompasses genetic species, assemblage, ecosystem and land cape levels of biological organization with structural, compositional and functional components [3,4]. Though loss of aquatic species has been occurring rapidly, the aquatic organisms have received comparatively little attention from conservation biologists [5]. A rich diversity of fish species is important to the ecology and sustainable productivity of the flood plains [6]. The resource of aquatic fauna in Bangladesh are

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under severe threat due to over-exploitation and environmental degradation, which includes human interventions through construction of flood control embankments, drainage structures and sluice gates, conversion of inundated land to cropland thereby reducing water area and indiscriminate use of pesticides. Pollution from domestic, industrial and agrochemicals wastes has resulted in extinction of a considerable amount of aquatic biota in some stretches of the open water system [7,8].

The upper region of the Mogra River is connected with Bisnai River and Kangshow River. The riverine flows across the Atpara and Modon Upazilla of Netrokona district from northern to southern Tharail and Itna Upazilla of Kishorgong District, before joining the Surma River. The water flow is continuous in the river. During monsoon, the water flow comes down from the upper region of Kangshow River and water flow does not confine within the banks. As a result, it causes floods in some area of Atpara and Modan Upazilla every year.

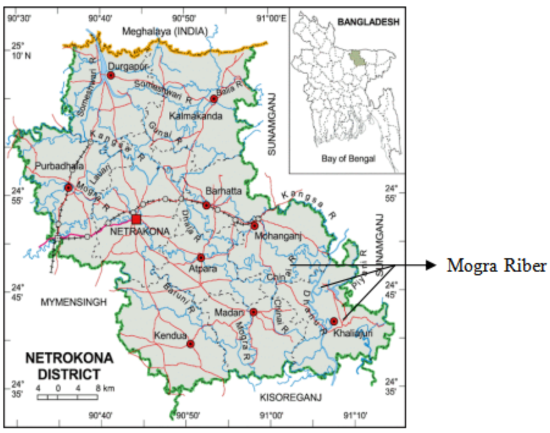

Figure 1. Location of Mogra River in the Netrokona district, Bangladesh.

Once upon a time, Mogra River was an abundance of native wild fishes, shrimp, crabs and reptiles. Due to over-exploitation and various ecological changes of the Mogra River, important fish species, and reptiles disappeared. Now this river is under great stress and its existence is endangered because of the changing aquatic ecosystems. The upper stream of the riverine system is siltated, which reduces the rate of water flow and causes habitat degradation. Like other floodplains, the feeding and breeding grounds of fishes in and around the river have been reducing drastically from various human created obstacles. Indiscriminate destructive fishing practices, soil erosion, siltation, construction of flood control and drainage structures, and agro-chemicals and pesticide have caused havoc to the aquatic biodiversity in Bangladesh.

2. Methodology

Experimental design

Mogra River was studied during 2015-2019 with particular emphasis on soil and water quality, biological productivity and status exploitation of the fishery resources. The river comprises an average length of 20-22 km long course. For the purpose of the study the river course was divided into upper and lower regions based on soil structure, water quality and fishing activities. The river courses of Atpara to Nazirgonj constitute the upper region while the Nazirgonj to Madon constituted the lower region, where in the Mogra River joins with the Surma River.

Study of water quality parameters

The bamboo made meter scale was used to measure water depth. Water temperature (^oC) was recorded using a Celsius thermometer and transparency (cm) was measured using a Secchi disc (20 cm diameter). Dissolved oxygen (mg/l) and pH were measured directly using a digital electronic oxygen meter (YSI, Model 58, USA) and an electronic pH meter (Jenway, Model 3020, UK). Alkalinity was determined following the titrimetric method.

Sampling of fish

The investigation was conducted from 2015-2019 and was sampled simultaneously for winter (mid November to mid February), pre monsoon (mid February to April), monsoon (May to August) and post monsoon (September to mid November) for assessment of fish abundance and availability.

Data collection

The study was based on both primary and secondary data, comprehensive literature review and extracts of local knowledge and information. An organized sampling program spread over a reasonably long time is needed to get a true picture of the catch and composition. This study, being a rapid survey, gives only a broad picture of the stock of fishes, prawn, crabs and turtiles that could be obtained through market survey (Brojer Bazar, Nazirgong Bazar, Teligati Bazar, Madon sadar Bazar) and interaction with fishers in the riverside and even in the river and secondary data were collected from the Department of Fisheries (DoF) and the internet. The number of six codes (CR, E, EN, VU, LR, LC and DD) of IUCN was followed to categorize the coservation of status of fishes recorded from the river and to compare the trend among Shannon index value of different years [9].

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Shannon Diversity Index

$$H = \sum_{i=1}^{S} - (P_i * \ln P_i)$$

Where:

H = the Shannon diversity index, P_i = fraction of the entire population made up of species i, S = numbers of species encountered, ∑ = sum from species 1 to species S.

Note: The power to which the base e (e = 2.718281828.) must be raised to obtain a number is called the natural logarithm (ln) of the number.

Analysis of experimental data

The data were analyzed through one way ANOVA using MSTAT followed by Duncan's Multiple Range Test to find out whether any significant difference existed among the different means [10].

3. Results and Discussion

Morphometry and hydrodynamics of experimental river

Generally, there are three main sources of water input into the river ecosystem viz. overspill from the higher river channel, surface flow and regeneration. Water flows were resolved by both rainfall and flooded water from the Meghaloya's hilly range, India. In upper region, this river is connected with Khongsa and Bisnai River. Flooding of the river originated from the Kangshow and Bisnai River. Surface run-off and increased in river height due to inflow of rainwater (flood) from the upper stretch, cause inundation of floodplains. The more water gain or exchange of water took place during southwest monsoon when floodplains were flooded. The early flood phase (April to June) occurred in the early monsoon when the water level in basin was relatively low. The water level in the floodplain rises and falls depending on the water level in adjacent rivers. The deep flood phase (June to September) began when the water level in the river, causing deep flooding in the four unions of Atpara and Madon Upazillas. Floodwater in flood plains began started receding in the post-monsoon season (October to December). The water loss by various means caused shrinkage of the effective water area and lowering of depth in the river which is very similar to the study of Chakraborty et al. [11].

Physical characteristics

Soil texture of the Mogra River bed varied from sandy to loam sand. Soil texture of upper river bed was having 90.80±6.02 sandy, 7.30±2.43 loam sand and 1.9±1.72% clay. The dominance of sand (58.30±5.18) was also recorded in the lower region of the river (Table 1).

Table 1. Physical features of sediment of the Mogra River.

Location	Soil texture of the river bed (%)		
	Sandy	Loam sand	Clay
Upper region	40.20±4.32	43.60±5.03	17.4±3.22
Lower region	38.30±4.18	42.10±4.06	19.60±3.54

The waterw depth of the Mogra River exhibited a decreasing with an average value of 3.55±0.64 3.41±0.55, 3.321±0.584 3.207±0.44 and 3.01±0.41 m during the study period (Figure 2). The highest depth of the river was recorded in the year 2015 and the lowest depth was found in the year 2019 and the equation of the trend line was $y= -0.128x +3.684$ ($R^2 = 0.981$). The alarming trend of decrease in water depth (Figure 2) was majorly due to rapid siltation [11]. The observed values of the value of the physico-chemical parameters of the river water are given in Table 2. The temperature, transparency, pH, dissolve oxygen and alkalinity of water were found to be more or less in the desired range. The variations in mean water temperature of the river were not statistically significant ($P>0.05$). Water temperature of the river showed an increasing trend in monsoon and post monsoon and decreasing trend in winter which was similar observation of Mathew [12]. Mean Secchi disk transparency differed significantly ($P<0.05$), during the study period. Higher values were recorded during post monsoon and summer months due to reduced flow and relatively stable conditions of water as observed by others [13]. The pH of the studied river did not differ significantly ($P>0.05$). Transparency was consistently higher in upper region and in the deeper portion of the river. A significant rise in pH during pre-monsoon and a drop in winter was noted in the river. The mean dissolved oxygen (DO) did not differ significantly ($P>0.05$). The pH and oxygen values of the river agreed more or less similar with the findings of APHA [14] and Boyd [15]. Water alkalinity levels were recorded medium to high as reported by Clesceri et al. [16]. It differed significantly ($P<0.05$) with time. Lowest value of alkalinity was recorded in the in the winter during 2015.

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Table 2. Physico-chemical parameters of experimental Mogra River.

Parameters	Years				
	2015	2016	2017	2018	2019
Temperature (°C)	25.74±5.01 (14.04-32.20)	26.17±6.12 (13.73-32.40)	26.48±6.08 (14.11-31.85)	26.88±6.26 (14.00-32.01)	26.14±5.88 (14.15-32.08)
Transparency (cm)	40.04±6.24^{d} (30.10-50.16)	50.38±7.02^{a} (32.22-58.14)	44.55±6.41^{c} (28.15-50.30)	37.19±6.88^{e} (27.55-50.25)	47.23±6.74^{b} (29.55-55.22)
pH	7.05± 2.04 (6.90-8.86)	7.66±2.22 (6.80-8.88)	8.05±2.03 (6.85-9.07)	7.77±1.88 (6.90-8.88)	8.08±2.01 (6.75-8.90)
Dissolved oxygen (mg/L)	6.95±1.84 (4.18-8.04)	8.84±1.88 (4.55-9.05)	7.70±1.99 (5.44-8.66)	7.22±1.72 (5.41-8.05)	7.09±1.96 (5.04-8.48)
Alkalinity (mg/L)	142.02±10.04^{a} (111.22-151.05)	120.66±7.22^{e} (110.88-135.02)	126.18±7.05^{d} (107.22-138.15)	131.52±8.07^{c} (110.40-140.32)	136.38±7.04^{b} (111.16-144.55)

Figures with different superscripts in the same row varied significantly (P>0.05).
Figures in the parenthesis indicate the range.

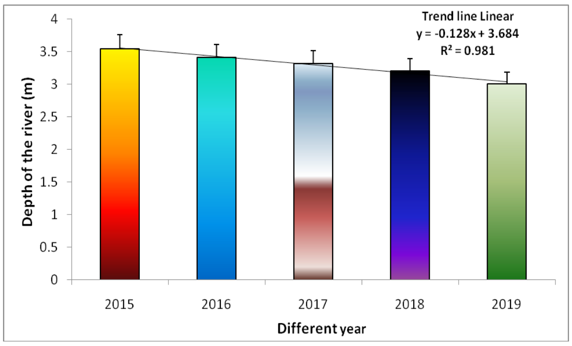

Figure 2. Water depth of the Mogra River between the year 2015 and 2019

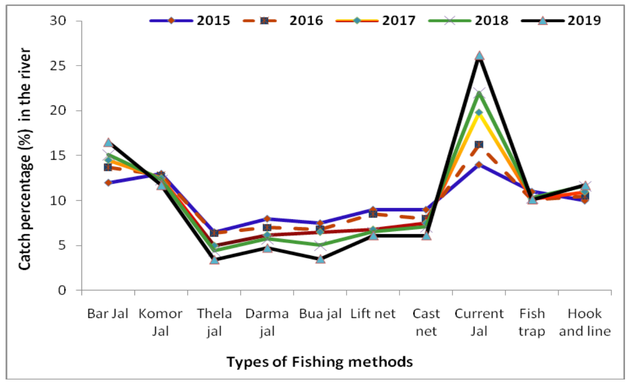

Figure 3. Contribution of different fishing gears during the study period (2015- 2019).

Capture method

The fishers used wooden boats as a major craft. They used seine net (Bar jal and Komor jal), Thela jal, Dharma jal, Bua jal, Lift net, Cast net, Current jal and various types of fish Trap, Hook and Line according to season and availability of different species of fishes. Wide variability in fish traps (vair, dugair, ghuni and pholo etc.) and hook and line (barshi, fulkuichi, Jhupi aikra etc.) were used to capture different groups of aquatic lives.

Figure 3 shows a remarkable yearly increase in fishing effort by using illegal fishing gear like gill net (Current jal) and Bar jal (kaperi jal) in the total catch. The percentage of catch from Current jal were 14.00%, 16.20%, 19.80%, 22.00% and 26.20%; and Bar jal (kaperi jal) 12.00%, 13.70%, 14.50%,15.10% and 16.50%; and Hook and line 10.00, 10.50, 11.00, 11.60 and 11.70% in the year 2015, 2016, 2017, 2018 and 2019, respectively. Significant difference in catch (P<0.05) by Current jal and Bar jal (kaperi jal) and Hook and line were identified. The contribution of catch by Komor jal were 13.00%, 12.80%, 12.50%, 12.30% and 11.70% in the years 2015, 2016, 2017, 2018 and 2019, respectively.

Use of different fishing gears also differed significantly (P<0.05). Haroon et al. [17] reported eighteen types of fishing gears from the Sylhet sub-basin and thirteen types from Mymensingh sub-basin which is very similar to this study. The catch using Thela jal, Dharma jal, Bua jal, Lift net, Cast net, fish Trap and Hook and line were found decreasing and differed significantly (P<0.05). A decreasing trend in the catch of the river and its flood plains were recorded and the findings were similar to that of Chakraborty et al., and Sugunan and Bhattacharjya [11,18].

Fish catch and composition

An organized sampling program was run for a long time to get a real picture of the catch and composition of the river. The present investigation gave a broad picture of the stock of fishes and other aquatic lives obtained through market survey, landing center and interaction with fishers in the river. From the fishing activity in the Mogra River, occurrence of 104 species of fish, 09 species of prawn, 01 species of snail and 04 species of crabs, and 13 species of turtles belonging to a total 26 families were recorded. Fishing activity run throughout the year. During monsoon and post monsoon, fishers used Lift net, Current jal, Cast net, Traps, and line and Hooks to catch fishes. Fishermen also operated kata fishing by seine net (Bar jal and Komor jal) in winter and spring. The catch is consisted of knife fish, major carp and minor carp, small fish, cat fish and small cat fish, eels, prawn, crabs and reptiles (Table 3 and Figure 4). The assessment of yearly total catch from the river was around 170.63±10.81 mt, 159.93±9.80 mt 150.98±10.66 mt, 143.16±9.80 ton and 134.75±8.02 mt during 2015, 2016, 2017, 2018 and 2019, respectivly (Figure 5). The catch trend line was exponential type and the equation was $y = 180.3e^{-0.05x}$ ($R^2 = 0.999$).

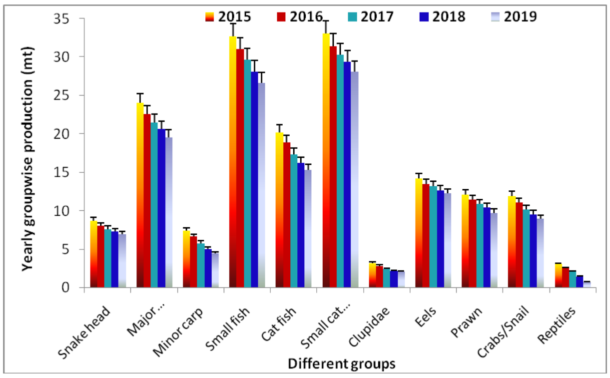

Figure 4. The production of different groups of aquatic lives in the Mogra River in the year 2015 to 2019.

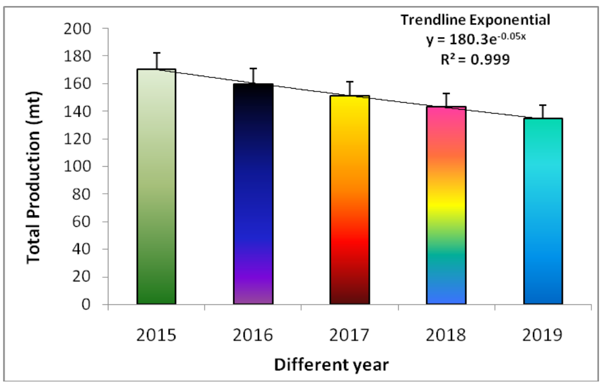

Figure 5. Decreasing trend in the total production of aquatic lives in the Mogra River during 2015 to 2019.

The fish catch showed a decrease percentage at the rate of 6.26%, 11.52%, 16.10% and 21.03% of catch in the years 2015-2016, 2016-2017, 2017-2018 and 2018-2019, with respect to the catch of 2015 (Figure 6) and which exhibited a linear trend line and the equation was $y = 4.889x + 1.5.5$ ($R^2 = 0.999$). A decrease trend in production from the river was clearly pronounced within the study period of five years which was similar to the study of Chakraborty and Mirza [19,20] and Moyle and Leidy [21]. Although the production of all the recorded groups decreased during the study, it was pronounced more for reptiles.

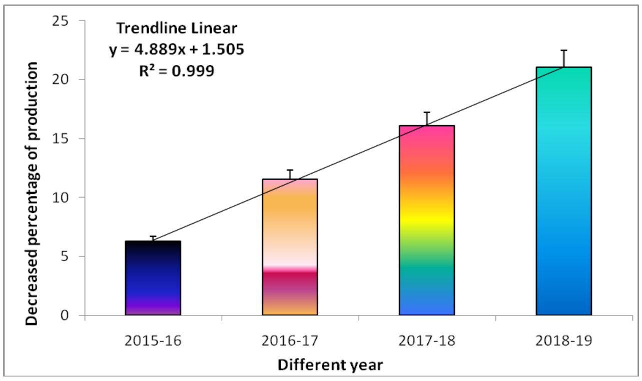

Figure 6. Decreasing percentage of total production of aquatic lives in the Mogra River during 2015 to 2019.

Table 3 and Figure 7 exhibited the conservation status of the 131 aquatic wild animals of the Mogra River and identified as E- 04 (3%), CR-17 (12%), EN-67 (51%), VU-20 (15%), LR-11 (9%), LC-7 (9%) and DD-06 (4%), respectively.

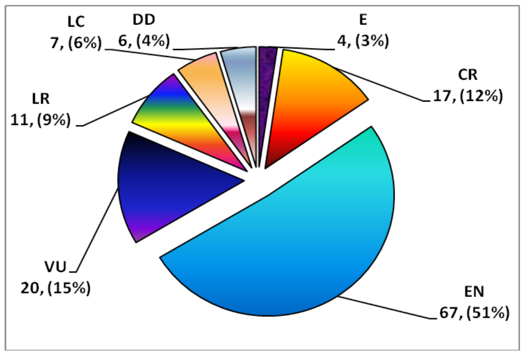

Figure 7. Conservation status of the recorded aquatic species in the Mogra River.

Status code: E- Extinct, CR- Critically Endangered, EN- Endangered, VU- Vulnerable, LR- Lower risk, LC- Not threatened DD=Data deficient (As per IUCN [22]).

The total catch in different years differed significantly ($P<0.05$). Commercial important Pata Kachim*, Cyclemys oldhami,* Kali Kachhap, *Melanocheelys trjuuga* and Bengal Eyed Turtile, *Morenia petersi* were rarely found in the years 2015 to 2017 in the river. However these species were not recorded during 2019. *Channa marulius, Puntius sarana, Barilius tileo, Sicamugil casoasia, Rohtee cotio*, *Bagarius yarrellii, Mystus seenghala, Bagarius yarrellii, Chaca chaca, Rama chandramara, Sisor rabdophorus, Pseudolaguvia muricata, Pseudolaguvia inornata* and reptiles (*Indotestudo elongata, Batagur baska, Geoclemys hamiltonii* and *Pangshura tecta* (17 species) were reported as critically endangered and facing an extremely high risk of extinction in the river system (Table 3). According to IUCN [23], in Bangladesh, about 56 freshwater fish species are critically or somewhat endangered. Due to Over

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Table 3. Status and distribution of Mogra River of northern Bangladesh.

SL No	Group/ Family	Local name	Scientific name	Production (mt)					Status
				Someswari River					
				2015	2016	2017	2018	2019	
Snake headed									
1	Notopteridae	Chitol	*Notopterus chitala*	0.70 ±0.09	0.65 ±0.05	0.59 ±0.05	0.54 ±0.03	0.50 ±0.02	EN
2	Notopteridae	Foli	*Notopterus notopterus*	0.50 ±0.04	0.44 ±0.03	0.37 ±0.02	0.33 ±0.01	0.30 ±0.01	EN
3	Belonidae	Kakila	*Xenentodon cancila*	1.90 ±0.44	1.70 ±0.40	1.55 ±0.41	1.38 ±1.10	1.26 ±0.07	LR
4	Channidae	Gojar	*Channa marulius*	0.60 ±0.20	0.53 ±0.09	0.50 ±0.07	0.48 ±0.05	0.44 ±0.03	CR
5	Channidae	Soal	*Channa striata*	1.03 ±0.51	1.00 ±0.10	0.97 ±0.08	0.98 ±0.09	0.92 ±0.06	EN
6	Channidae	Gachua	*Channa gachua*	1.88 ±0.50	1.70 ±0.50	1.68 ±0.44	1.66 ±0.42	1.62 ±0.41	CR
7	Channidae	Taki	*Channa punctata*	2.08 ±0.60	2.00 ±0.55	1.98 ±0.50	1.95 ±0.44	1.90 ±0.42	LR
SubTotal				**8.89 ±0.69**	**8.02 ±0.68**	**7.64 ±0.64**	**7.32 ±0.63**	**6.94 ±0.62**	
Major carps									
1	Cyprinidae	Catla	*Catla catla*	1.98 ±0.80	1.84 ±0.65	1.80 ±0.60	1.73 ±0.54	1.65 ±0.50	EN
2	Cyprinidae	Rui	*Labeo rohita*	3.01 ±0.30	2.88 ±0.30	2.81 ±0.30	2.71 ±0.27	2.60 ±0.21	EN
3	Cyprinidae	Mrigal	*Cirrhinus mrigala*	3.04 ±0.26	3.0 ±0.24	2.97 ±0.22	2.90 ±0.21	2.78 ±0.20	EN
4	Cyprinidae	Kalbaus	*Labeo calbasu*	2.3 ±0.19	2.25 ±0.18	2.21 ±0.17	2.16 ±0.10	2.07 ±0.10	EN
5	Cyprinidae	Ghonia	*Labeo gonius*	2.80 ±0.17	2.50 ±0.16	2.30 ±0.14	2.20 ±0.11	1.97 ±0.10	EN
6	Cyprinidae	Reba	*Cirrhinus reba*	1.80 ±0.11	1.60 ±0.10	1.40 ±0.09	1.20 ±0.08	1.10 ±0.06	EN
7	Cyprinidae	Common carp	*Cyprinus carpio*	5.50 ±1.84	5.20 ±1.70	5.00 ±1.22	4.80 ±1.10	4.50 ±1.00	VU
8	Cyprinidae	*Grass carp*	*Ctenopharyngodon idella*	3.60 ±1.24	3.30 ±1.11	3.00 ±1.01	2.95 ±1.00	2.88 ±0.98	VU
Sub-Total				**24.03±1.17**	**22.57±1.12**	**21.49±1.09**	**20.65 ±1.08**	**19.55 ±1.03**	
Minor carp									
1	Cyprinidae	Along	*Bengala elanga*	1.20 ±0.07	1.10 ±0.06	0.94 ±0.04	0.82 ±0.03	0.69 ±0.01	VU
2	Cyprinidae	Bhangna bata	*Labeo bata*	1.10 ±0.06	1.00 ±0.05	0.80 ±0.05	0.65 ±0.04	0.50 ±0.02	EN
3	Cyprinidae	Ghora muikha	*Labeo pangusia*	1.82 ±0.05	1.80 ±0.05	1.70 ±0.04	1.60 ±0.03	1.50 ±0.03	EN
4	Cyprinidae	Jarua/Utti	*Chagunius chagunio*	0.87 ±0.06	0.70 ±0.05	0.62 ±0.03	0.48 ±0.03	0.38 ±0.01	EN
5	Cyprinidae	Puda	*Puntius sarana*	0.58 ±0.04	0.45 ±0.03	0.22 ±0.02	0.12 ±0.01	0.01 ±0.01	CR
6	Cyprinidae	Tila koksa	*Barilius tileo*	1.01 ±0.08	0.90 ±0.05	0.88 ±0.04	0.84 ±0.03	.81 ±0.01	EN
7	Cyprinidae	Bhol	*Raimass bola*	0.86 ±0.05	0.72 ±0.04	0.64 ±0.04	0.55 ±003	0.54 ±0.01	EN
Sub-Total				**7.74 ±0.39**	**6.67 ±0.43**	**5.80 ±0.45**	**5.06 ±0.47**	**4.43 ±0.46**	
Small fish									
1	Cyprinidae	Mola	*Amblypharyngodon mola*	1.88 ±0.07	1.77 ±0.06	1.64 ±0.05	1.53 ±0.05	1.45 ±0.03	EN

2	Cyprinidae	Barna Baril/ Koksa	*Barilius barna*	1.20 ±0.05	1.00 ±0.04	1.10 ±0.04	0.96 ±0.02	0.90 ±0.03	EN
3	Cyprinidae	Baril	*Barilius bendelisis*	0.66 ±0.03	0.59 ±0.01	0.55 ±0.01	0.50 ±001	0.46 ±0.01	EN
4	Cyprinidae	Koksa	*Barilius shacra*	0.55 ±0.02	0.52 ±0.02	0.49 ±0.02	0.45 ±0.01	0.41 ±0.01	EN
5	Cyprinidae	Koksa	*Barilius tileo*	0.88 ±0.03	0.87 ±0.03	0.84 ±0.03	0.80 ±0.01	0.78 ±0.0	CR
6	Cyprinidae	Aspidopara/ Morar	*Aspidoparia morar*	0.66 ±0.04	0.62 ±0.04	0.60 ±0.03	0.58 ±0.02	0.55 ±0.01	EN
7	Cyprinidae	Chepchela	*Chela cachius*	0.80 ±0.05	0.75 ±0.04	0.66 ±0.03	0.62 ±0.03	0.58 ±0.02	EN
8	Cyprinidae	Kashkhaira	*Chela laubuca*	0.90 ±0.06	0.88 ±0.04	0.84 ±0.04	0.81 ±0.03	0.78 ±0.03	EN
9	Mugillidae	Kachi Kholya	*Sicamugil casoasia*	0.66 ±0.02	0.60 ±0.01	0.58 ±0.01	0.55 ±001	0.52 ±0.01	CR
10	Cyprinidae	Baspata	*Danio devario*	0.55 ±0.03	0.52 ±0.03	0.48 ±0.03	0.45 ±0.02	0.43 ±0.01	EN
11	Cyprinidae	Dhela	Rohtee *cotio*	0.50 ±0.03	0.40 ±0.02	0.32 ±0.02	0.22 ±0.01	0.12 ±0.0	CR
12	Cyprinidae	Chola punti	*Puntius chola*	0.66 ±0.04	0.63 ±0.04	0.62 ±0.03	0.61 ±0.02	0.60 ±0.02	EN
13	Cyprinidae	Taka punti	*Puntius conchonius*	0.70 ±0.05	0.68 ±0.05	0.64 ±0.04	0.60 ±0.03	0.58 ±0.02	EN
14	Cyprinidae	Phutani punti	*Puntius phutunio*	0.80 ±0.05	0.78 ±0.05	0.75 ±0.02	0.72 ±0.02	0.68 ±0.01	EN
15	Cyprinidae	Jatpunti Punti	*Puntius Sophore*	0.44 ±0.03	0.42 ±0.03	0.40 ±0.02	0.37 ±0.02	0.34 ±0.01	EN
16	Cyprinidae	Teri punti	*Puntius terio*	0.70 ±0.04	0.67 ±0.04	0.65 ±0.03	0.63 ±0.02	0.60 ±0.02	EN
17	Cyprinidae	Tit Punti	*Puntius ticto*	0.83 ±0.05	0.80 ±0.05	0.77 ±0.04	0.74 ±0.03	0.70 ±0.02	VU
18	Cyprinidae	Fulchela	*Salmostoma phulo*	0.78 ±0.04	0.75 ±0.04	0.73 ±0.03	0.70 ±0.02	0.68 ±0.02	EN
19	Cyprinidae	Darkina	*Esomus danricus*	0.50 ±0.03	0.48 ±0.02	0.45 ±0.02	0.42 ±0.02	0.12 ±0.01	VU
20	Cyprinidae	Kanpona	*Oryzias melastigma*	1.00 ±0.03	0.98 ±0.03	0.95 ±0.03	0.92 ±0.02	0.88 ±0.01	VU
21	Clupeidae	Kachki	*Corica soborna*	0.40 ±0.03	0.38 ±0.02	0.36 ±0.02	0.28 ±0.02	0.23 ±0.01	DD
22	Cobitidae	Balitora	*Psilorhynchus balitora*	0.40 ±0.02	0.40 ±0.02	0.37 ±0.02	0.35 ±0.01	0.33 ±0.01	EN
23	Cobitidae	Balitora	*Psilorhynchus rahmani*	0.37 ±0.02	0.36 ±0.01	0.22 ±0.01	0.09 ±001	0.08 ±0.01	LC
24	Cobitidae	River stone carp/ Titari	*Psilorhynchus sucatio*	0.70 ±0.07	0.66 ±0.06	0.64 ±0.04	0.63 ±0.05	0.60 ±0.03	EN
25	Cobitidae	Bilturi /Bali chata	*Acanthocobitis botia*	0.50 ±0.03	0.47 ±0.03	0.44 ±0.02	0.42 ±0.02	0.38 ±0.01	EN
26	Cobitidae	River loach/ Balichata	*Acanthocobitis zonalternans*	0.70 ±0.05	0.68 ±0.04	0.64 ±0.03	0.60 ±0.02	0.56 ±0.03	VU
27	Cobitidae	Koirka	*Nemacheilus corica*	0.60 ±0.04	0.58 ±0.03	0.56 ±0.02	0.53 ±0.01	0.50 ±0.2	LR
28	Cobitidae	Creek loach	*Schistura beavani*	0.40 ±0.03	0.38 ±0.04	0.36 ±0.03	0.35 ±0.02	0.32 ±0.02	VU
29	Cobitidae	Corica Loach/ Korika	*Schistura corica*	0.70 ±0.05	0.66 ±0.05	0.63 ±0.05	0.60 ±0.04	0.57 ±0.04	LR
30	Cobitidae	Savon khorka	*Schistura savona*	0.66 ±0.04	0.62 ±0.03	0.60 ±0.03	0.57 ±0.02	0.55 ±0.02	LR
31	Cobitidae	Dari	*Schistura scaturigina*	0.40 ±0.03	0.38 ±0.02	0.36 ±0.02	0.35 ±0.02	0.32 ±0.01	EN

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32	Cobitidae	Bengal loach / Bou mach	*Botia dario*	0.60 ±0.05	0.55 ±0.04	0.53 ±0.04	0.51 ±0.02	0.48 ±0.02	VU
33	Cobitidae	Hora loach	*Botia dayi*	0.60 ±0.05	0.58 ±0.04	0.56 ±0.03	0.53 ±0.03	0.50 ±0.01	EN
34	Cobitidae	Loach/ Puiya	*Lepidocephalichthys goalparensis*	0.90 ±0.05	0.88 ±0.04	0.85 ±0.02	0.83 ±0.02	0.81 ±0.02	EN
35	Cobitidae	Goalpara loach	*Neoeucirrhichthys maydelli*	0.55 ±0.04	0.52 ±0.04	0.50 ±0.03	0.48 ±0.02	0.45 ±0.01	EN
36	Cobitidae	Gonga loach/ Poia/ Ghar poia	*Somileptes gongota*	0.60 ±0.05	0.58 ±0.05	0.55 ±0.04	0.53 ±0.03	0.50 ±0.02	VU
37	Cobitidae	Rani	*Botia lohachata*	0.44 ±0.04	0.41 ±0.04	0.38 ±0.03	0.36 ±0.03	0.33 ±0.01	LR
38	Cobitidae	Rani	*Lepidocephalichthys annandalei*	0.55 ±0.03	0.53 ±0.03	0.52 ±0.02	0.50 ±0.02	0.47 ±0.02	EN
39	Cobitidae	Balichata	*Nemachilus botia*	0.77 ±0.04	0.74 ±0.04	0.73 ±0.02	0.71 ±0.03	0.68 ±0.03	EN
40	Centropomidae	Chanda	*Chanda nama*	1.50 ±0.08	1.47 ±0.05	1.44 ±0.04	1.36 ±004	1.28 ±0.03	LC
41	Centropomidae	Chanda	*Pseudambasis bacuculis*	1.20 ±0.08	1.16 ±0.06	1.15 ±0.05	1.13 ±0.04	1.08 ±0.04	EN
42	Centropomidae	Ranga chanda	*Pseudambasis ranga*	0.80 ±0.05	0.74 ±0.04	0.70 ±0.03	0.68 ±0.03	0.66 ±0.02	LC
43	Gobiidae	Baila	*Glossogobus giuris*	1.20 ±0.07	1.10 ±0.06	1.00 ±0.05	0.98 ±0.04	0.94 ±0.04	DD
44.	Tetradontidae	Potka	*Tetradon cutcutia*	1.50 ±0.08	1.44 ±0.07	1.44 ±0.06	1.36 ±0.04	1.32 ±0.04	EN
Sub-Total				**32.72 ±0.32**	**29.53±0.29**	**29.63±0.30**	**28.14 ±0.29**	**26.63 ±0.28**	
Cat fish									
1	Bagridae	Ayre	*Mystus aor*	2.20 ±0.12	2.10 ±0.11	2.00 ±0.10	1.98 ±0.10	1.90 ±0.09	EN
2	Bagridae	Guizza	*Mystus seenghala*	3.00 ±0.20	2.89 ±0.17	2.75 ±0.14	2.66 ±0.11	2.55 ±0.11	CR
3	Schilbeidae	Shilong	*Silonia silondia*	1.00 ±0.09	0.97 ±0.08	0.93 ±0.09	0.90 ±0.07	0.88 ±0.08	EN
4	Siluridae	Boal	*Wallago attu*	5.03 ±1.84	4.90 ±1.71	4.70 ±1.81	4.40 ±1.70	41.00 ±1.40	LR
5	Bagridae	Baghair	*Bagarius yarrellii*	2.08 ±0.80	1.66 ±0.70	1.20 ±0.7	1.11 ±0.68	1.00 ±0.65	CR
6	Chacidae	Cheka	*Chaca chaca*	1.50 ±0.10	1.30 ±0.09	1.00 ±0.08	0.96 ±0.08	0.90 ±0.05	CR
7	Bagridae	Gangmagur	*Mystus menoda*	2.85 ±0.90	2.55 ±0.80	2.33 ±0.78	2.00 ±0.74	1.88 ±0.60	EN
8	Bagridae	Rita	*Rita rita*	2.55 ±0.81	2.50 ±0.70	2.44 ±0.70	2.20 ±0.60	2.09 ±0.50	EN
Sub total				**20.21±1.21**	**18.87±1.22**	**17.35±1.24**	**16.21 ±1.15**	**15.30 ±1.08**	
Small cat fish									
1	Bagridae	Gulsa	*Mystus cavasius*	2.20 ±0.12	2.10 ±0.11	2.08 ±0.08	2.03 ±0.07	1.90 ±0.06	EN
2	Bagridae	Tengra	*Mystus vitttus*	2.70 ±0.11	2.60 ±0.11	2.50 ±0.10	2.45 ±0.10	2.40 ±0.08	EN
3	Bagridae	Bujuri	*Mystus tengra*	2.70 ±0.11	2.66 ±0.11	2.60 ±0.08	2.55 ±0.07	2.51 ±0.06	VU
4	Bagridae	Gura Tengra/ Futki bujuri	*Rama chandramara*	0.70 ±0.06	0.60 ±0.04	0.50 ±0.03	0.48 ±0.03	0.39 ±.0.02	CR
5	Bagridae	Menoda catfish /Arwari	*Hemibagrus menoda*	0.80 ±0.07	0.77 ±0.05	0.75 ±0.05	0.73 ±0.04	0.70 ±0.02	EN
6	Bagridae	Kerala mystus	*Mystus armatus*	0.90 ±0.04	0.85 ±0.04	0.80 ±0.03	0.75 ±0.03	0.70 ±.0.02	EN

7	Bagridae	Day's mystus/ Tengra	*Mystus bleekeri*	0.75 ±0.07	0.74 ±0.05	0.72 ±0.05	0.70 ±0.04	0.68 ±0.02	EN
8	Schilbeidae	Kajuli	*Ailia coila*	0.90 ±0.08	0.86 ±0.07	0.84 ±0.06	0.81 ±0.05	0.79 ±0.04	EN
9	Siluridae	Kani Pabda	*Ompok bimaculatus*	1.58 ±0.08	1.50 ±0.07	1.48 ±0.06	1.41 ±0.06	1.37 ±0.05	EN
10	Siluridae	Madhu Pabda	*Ompok pabda*	1.77 ±0.09	1.60 ±0.08	1.55 ±0.07	1.52 ±0.06	1.48 ±0.05	VU
11	Siluridae	*Ompok pabda*	*Ompok pabo*	1.20 ±0.06	1.17 ±0.05	1.14 ±0.06	1.10 ±0.04	1.00 ±0.04	EN
12	Schilbeidae	Gharua	*Clupisoma garua*	1.07 ±0.08	0.96 ±0.06	0.94 ±0.07	0.88 ±0.07	0.80 ±0.05	EN
13	Schilbeidae	Muri Bacha	*Clupisoma murias*	1.40 ±0.05	1.30 ±0.05	1.26 ±0.05	1.20 0.04	1.14 ±0.03	EN
14	Schilbeidae	Batasi	*Pseudeutropius atherinoides*	1.00 ±0.05	0.97 ±0.05	0.95 ±0.03	0.92 ±0.02	0.90 ±.0.02	VU
15	Schilbeidae	Bacha	*Eutropiichthys vacha*	0.90 ±0.04	0.88 ±0.05	0.85 ±0.04	0.83 ±0.04	0.80 ±0.02	EN
16	Sisoridae	Kutakanti	*Hara hara*	0.60 ±0.04	0.55 ±0.04	0.49 ±0.04	0.45 ±0.04	0.44 ±0.04	LR
17	Sisoridae	Kutakanti	*Hara jerdoni*	1.10 ±0.07	1.04 ±0.06	1.00 ±0.06	0.99 ±0.05	0.96 ±0.04	EN
18	Sisoridae	Gang tengra	*Nangra nangra*	0.90 ±0.04	0.88 ±0.03	0.85 ±0.04	0.82 0.04	0.79 ±0.03	VU
19	Sisoridae	Chenua	*Sisor rabdophorus*	0.35 ±0.02	0.30 ±0.02	0.25 ±0.03	0.16 ±0.02	0.08 ±.0.02	CR
20	Sisoridae	Conta catfish/ Kuta kanti	*Conta conta*	1.24 ±0.07	1.20 ±0.06	1.15 ±0.05	1.11 ±0.04	1.05 ±0.02	DD
21	Sisoridae	Kutakanti	*Erethistes pusillus*	1.00 ±0.02	0.97 ±0.02	0.93 ±0.01	0.12 ±0.01	0.10 ±.0.01	VU
22	Sisoridae	Kani Tengra	*Pseudolaguvia muricata*	0.55 ±0.04	0.50 ±0.03	0.46 ±0.04	0.43 ±0.03	0.34 ±0.02	CR
23	Sisoridae	Chanua	*Pseudolaguvia inornata*	1.44 ±0.09	1.33 ±0.08	1.32 ±0.06	1.32 ±0.05	1.29 ±0.05	CR
24	Clariidae	Cat fish/ Magur	*Clarias batrachus*	0.50 ±0.03	0.47 ±0.03	0.45 ±0.03	0.43 ±0.02	0.40 ±.0.02	VU
25	Heteropneustidae	Stinging catfish/ Shingi	*Heteropneustes fossilis*	1.44 ±0.07	1.38 ±0.05	1.32 ±0.05	1.30 ±0.04	1.26 ±0.02	LC
26	Chacidae	Cheka	*Chaca chaca*	1.70 ±0.10	1.60 ±0.09	1.15 ±0.08	1.47 ±0.05	1.33 ±.0.05	LR
27	Olyridae	Gagora catfish / Gobi	*Arius gagora*	1.48 ±0.07	1.40 ±0.06	1.35 ±0.05	1.32 ±0.04	1.27 ±0.02	EN
Sub-total				**33.03±0.60**	**31.45±0.58**	**30.31±0.57**	**29.41 ±0.57**	**28.09 ±0.56**	
Clupidae									
1	Clupidae	Chapila	*Gadusia chapra*	1.80 ±0.08	1.50 ±0.07	1.12 ±0.06	1.00 ±0.05	1.00 ±0.04	EN
2	Clupidae	Hilsa	*Tenualosa ilisha*	0.98 ±0.08	0.95 ±0.06	0.90 ±0.04	0.85 ±0.02	0.82 ±0.01	EN
3	Clupidae	Gizzard shad/ Chapila	*Gonialosa manmina*	0.44 ±0.08	0.38 ±0.06	0.34 ±0.04	0.31 ±0.02	0.28 ±0.01	EN
Subtotal				**3.22 ±0.68**	**2.83 ±0.56**	**2.44 ±0.44**	**2.16 ±0.36**	**2.10 ±0.38**	
Eels									
1	Mastacembeli-dae	Baim	*Mastacembalus armatus*	3.44 ±0.14	3.35 ±0.11	3.33 ±0.09	3.24 ±0.08	3.12 ±0.07	VU
2	Synbranchidae	Kuicha	*Monopterus cuchia*	3.09 ±0.10	2.98 ±0.10	2.91 ±0.09	2.80 ±0.08	2.27 ±0.08	EN
3	Mastacembelidae	Lesser spiny eel/ Tara baim	*Macrognathus aculeatus*	2.90 ±0.13	2.83 ±0.12	2.76 ±0.10	2.63 ±0.10	2.54 ±0.09	EN

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4	Mastacembelidae	One-stripe spiny eel	*Macrognathus aral*	2.20 ±0.12	2.00 ±0.11	1.95 ±0.09	1.91 ±0.08	1.86 ±0.07	LR
5	Mastacembelidae	Barred spiny eel/ Pankal baim	*Macrognathus pancalus*	2.55 ±0.13	2.30 ±0.12	2.22 ±0.12	2.12 ±0.11	2.04 ±0.10	EN
Subtotal				**14.18 ±0.48**	**13.44 ±0.54**	**13.17 ±0.55**	**12.70 ±0.53**	**12.26 ±0.51**	
Prawn									
1	Palaemonidae	Golda Isa	*Machrobrachiu rosenbergii*	1.83 ±0.07	1.77 ±0.06	1.68 ±0.05	1.60 ±0.05	1.47 ±0.04	EN
2	Palaemonidae	Gura Isa	*Machrobrachium biramanicus*	2.50 ±0.18	2.42 ±0.16	2.35 ±0.15	2.28 ±0.14	2.20 ±0.15	DD
3	Palaemonidae	Gul Isa	*Machrobrachium malcolmsnii*	1.61 ±0.09	1.44 ±0.05	1.32 ±0.05	1.25 ±0.04	1.18 ±0.04	VU
4	Palaemonidae	Dimua icha	Macrobrachium villosimanus	1.90 ±0.20	1.80 ±0.11	1.71 ±0.10	1.64 ±0.09	1.57 ±0.10	LC
5	Palaemonidae	Gura icha or kuncho chingri	Macrobrachium lamarrei	0.88 ±0.22	0.79 ±0.16	0.80 ±0.15	0.77 ±0.14	0.75 ±0.16	LR
6	Palaemonidae	Kaira icha or beel chingri.	Macrobrachium dayanum	0.71 ±0.06	0.66 ±0.03	0.60 ±0.03	0.60 ±0.02	0.54 ±0.02	LR
7	Palaemonidae	Chikna chingri.	Macrobrachium idella	0.92 ±0.02	0.88 ±0.02	0.82 ±0.01	0.77 ±0.01	0.59 ±0.01	DD
8	Palaemonidae	Icha	Macrobrachium kempi	0.87 ±0.08	0.82 ±0.07	0.78 ±0.04	0.75 ±0.04	0.72 ±0.02	VU
9	Palaemonidae	chingri	Macrobrachium superbum	0.90 ±0.06	0.84 ±0.04	0.86 ±0.03	0.80 ±0.02	0.73 ±0.02	LC
Sub-total:				**11.12 ±0.63**	**11.42 ±0.62**	**10.92 ±0.60**	**10.46 ±0.57**	**7.75 ±0.56**	
Crabs/Snail									
1	Potamidae	Kakra	*Sartoriana spinigera*	2.77 ±0.80	2.73 ±0.61	2.54 ±0.53	2.46 ±0.48	240 ±0.40	DD
2	Grapsidae	Common Kakra	*Lobothelphusa wood-masoni*	2.60 ±0.06	2.40 ±0.08	2.33 ±0.05	2.10 ±0.08	1.88 ±0.04	LR
3	Grapsidae	Kakra	*Acanthopotamon martensi*	2.48 ±0.08	2.33 ±0.07	2.12 ±0.06	2.00 ±0.04	1.90 ±0.03	VU
4	Parathelphusidae	Kakra	*Pyxidognathus fluviatilis*	1.08 ±0.03	0.92 ±0.03	0.88 ±0.02	0.82 ±0.02	0.78 ±0.01	LC
5	Parathelphusidae	Kakra	*Austrotelphusa transversa*	1.88 ±0.04	1.72 ±0.05	1.44 ±0.04	1.34 ±0.03	1.22 ±0.01	EN
6	Unionidae	Bivalve	*Lamellidens marginalis*	1.12 ±0.04	1.00 ±0.03	0.90 ±0.02	0.85 ±0.02	0.79 ±0.01	VU
Sub-total:				**11.93 ±0.75**	**11.10 ±0.76**	**10.21 ±0.72**	**9.57 ±0.70**	**8.97 ±0.67**	
Reptiles									
1	Testudinidae	Elongated Tortoise/ Kachhap	*Indotestudo elongata*	0.29 ±0.03	0.22 ±0.02	0.19 ±0.02	0.13 ±0.01	0.09 ±0.01	CR
2	Testudinidae	Asian Giant Tortoise/ Chila Kachhap	*Manouria emys*	0.35 ±0.04	0.32 ±0.03	0.21 ±0.02	0.18 ±0.02	0.11 ±0.01	EN
3	Geoemydidae	River Terrapin /Bodo Kaitta	*Batagur baska*	0.16 ±0.02	0.13 ±0.01	0.09 ±0.01	0.05 ±0.01	0.01 ±0.00	CR
4	Geoemydidae	Painted Roofed Turtile/Dhoor Kachim	*Batagur dongoka*	0.18 ±0.02	0.14 ±0.02	0.11 ±0.01	0.08 ±0.01	0.03 ±0.07	EN
5	Geoemydidae	Oldham,s Leaf Turtile/ Pata Kachim	*Cyclemys oldhami*	0.26 ±0.02	0.20 ±0.02	0.14 ±0.01	010 ±0.01	0.00 ±0.00	E
6	Geoemydidae	SpottedTurtile/ Kala Kachim	*Geoclemys hamiltonii*	0.19 ±0.03	0.14 ±0.02	0.12 ±0.01	0.10 ±0.01	0.07 ±0.01	CR
7	Geoemydidae	Brahminy River Turtile/Kali Kaitta	*Hardella thurjii*	0.30 ±0.11	0.24 ±0.05	0.18 ±0.06	0.13 ±0.02	0.07 ±0.01	EN
8	Geoemydidae	Shila Kachhap	*Melanocheelys tricarinata*	0.30 ±0.02	0.26 ±0.01	0.19 ±0.01	0.15 ±0.01	0.08 ±0.00	EN

9	Geoemydidae	Snail Eating Turtile/ Kali Kachhap	*Melanocheelys trjuuga*	0.40 ±0.02	0.35 ±0.02	0.30 ±0.01	0.10 ±0.00	0.00 ±0.00	E
10	Geoemydidae	Bengal Eyed Turtile	*Morenia petersi*	0.08 ±0.01	0.06 ±0.01	0.05 ±0.01	0.04 ±0.00	0.0 ±0.00	E
11	Geoemydidae	Indian Turtile/ Kori Kaitta	*Pangshura tecta*	0.13 ±0.02	0.10 ±0.01	0.10 ±0.01	0.09 ±0.01	0.07 ±0.01	CR
12	Geoemydidae	Tent Turtile/ Majhari Kaitta	*Pangshura tentoria*	0.07 ±0.01	0.06 ±0.01	0.06 ±0.00	0.05 ±0.01	0.04 ±0.00	EN
13	Trionychidae	Ganges Turtile/ Khalua Kachim	*Aspideretes gangeticus*	0.35 ±0.03	0.32 ±0.02	0.30 ±0.03	0.28 ±0.02	0.16 ±0.01	VU
Sub-total				**3.06 ±0.11**	**2.54 ±0.10**	**2.04 ±0.08**	**1.48 ±0.06**	**0.73 ±0.05**	
			Total	**170.63 ±8.81**	**159.93 ±7.40**	**150.98 ±6.66**	**143.16 ±5.87**	**134.75 ±5.02**	

exploitation and various ecological changes in natural aquatic ecosystem of river and its floodplains, commercially important aquatic lives are in the verge of extinction which is in agreement with the findings of Sarker [24].

The total catch data of the river exhibited a constant sharp decrease during 2015 and 2019. Some of the important native species were noted to be losing their presence. The capture of fishes, crab and reptiles in the river was recorded highest in 2015-16, but decreased considerably in 2017-2018 and the similar situation continued in 2018-2019. Small catfishes and small fishes are dominant groups caught from the river. The observation was similar to the findings of Chakraborty and Mirza [20], Chakraborty [25] and Chakraborty et al. [26,11]. As a result, commercially important three aquatic lives of river were recorded to be disappearing during this short 5 years experimental period.

A decreasing trend in catch of the river was clearly recorded within five years which was similar to the report of Chakraborty and Mirza [19] and Moyle and Leidy [21]. A total of thirteen species of fresh water turtles were found in the Mogra River and its floodplain. Khan [27] reported that *Pangshura tecta* are mainly distributed between the stretches of the Ganges River and the Brahmaputra River. Bengal Eyed turtle, *Morenia petersi* was found in the rivers and its flood plains wetland. Das [28] mentioned its occurrence in Assam of India. *Morenia petersi* was regularly caught by fishermen and expert tribal hunters. Unfortunately, three important species of turtles became rare in their existence as per the catch data, within five years study period.

The population of bivalve, *Lamellidens marginalis* as found in the river and its flood plains has also been decreasing which is considered with the observation of Ali [29] and Chakraborty [25]. During the study period, fresh water pearl bearing mussels (Bivalve, *Lamellidens marginalis*) were identified in the river. Shells of bivalve were utilized by rural people for production of lime which was utilized in aquaculture and agriculture land, and consumed with betel leaves and nuts.

The wildlife comprises amphibians (*Bufo melanostictus*, *Rana tigerina*, *Rana limnocharis*, *Rana cyanophyctis* and *Salamandra salamandra* etc.) aves (whistling duck, great crested grebe, great cormorant, red crested pochard, water cock, swamphen, great black headed gull, gray-headed fish eagle, curlew, spotted redshank etc.) and mammals (musk shrew, fishing cat, small Indian jackal, flying fox etc.) were previously reported by Chakraborty et al. [26].

The study clearly indicates that the aquatic lives of the river were subjected to over exploitation resulting in gradual decline in their catch. The stock of aquatic animals is reducing due to pollution and destructive fishing practices [30,31,11]. Indiscriminate killing of fish occurred due to the use of pesticides in improper doses[6], use of forbidden chemicals, and aerial spray of chemicals as used in paddy field which was very much similar to the observation of Chakraborty [31] and Mazid [32]. Intervention to control floods, adoption of new agricultural technologies and construction of road networks altered the ecology of rivers and its flood plains significantly which supported the views of Khan [33] and Ali [29]. Decreased stock of the wild brood fishes in their breeding ground also resulted in a reduction of biodiversity as noted by Nishat [34], Zaman [35] and Chakraborty [36].

4. Conclusions

To save the stock of aquatic species in the river, a team of local management committee like Hilsa fisheries management technology is needed to develop a working frame-work. The deeper area of the river must be declared as a sanctuary to protect the aquatic lives, stricken enforcement of fish Act-1950 in the river, ensured stopping unplanned construction of flood control embankments, drainage system and sluice gates, conversion of inundated land to cropland (reducing water area); and controlling use of pesticides and agrochemicals in the floodplains of the river can save the ecosystems. The sustained produc-

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tion level from the river will also ensure livelihood of the fishers.

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ARTICLE

Abundance and Distribution, Growth Pattern, Sex Ratio and Gonadosomatic Index (GSI) of *Liza falcipinnis* (Valenciennes, 1836) from Ojo Axis of Badagry Creeks, Lagos, Nigeria

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ABSTRACT

A study on seasonal abundance, morphometric and meristic data, growth pattern, condition factor, sex ratio and gonadosomatic index of Liza falcipinnis (Valenciennes, 1836) from the Ojo axis of Badagry creek, Nigeria was conducted from May 2019 to March 2020. A total of 1012 species were randomly selected, having 499 females and 513 males. The length frequency analysis and length-weight relationships (LWR) were determined. Sex ratio was determined by Chi-square analysis. The results showed that morphometric data are: 0.5 - 2.5 mm for ED, 2.1 - 12 mm for HL, 1.7 - 8.1 mm for HD, 2.5 - 11.7 for BD, 2.6 - 233.3 mm for TL and 9.23 - 1006 g for BW for the combined sexes. The slope (b) shows an allometric growth pattern. The intercept 'a' and slope 'b' of the LWR (LogW = a + bLogL) were Log W= 15.39+ 0.34 LogL (r= 0.54) for combined sexes, Log W= 12.49+ 0.02 log L (r= 0.38) for males and Log W= 18.23+ 0.01 log L (r=0.16) for females. The length frequency distribution indicated that species were dominated by two year classes (Ages 1 and 2). Condition factors were generally low. The values ranged between 0.68 - 0.85 for combined sexes. The gonadosomatic index for female was highest in August, 2019 (17.77%) with Mean±SD of 2.88±0.75; which indicated the peak of spawning period in the study area. Sex ratio difference was significant (P<0.05). Sexual differences were significant; the females are phenotypically larger than the male.

1. Introduction

Liza falcipinnis, is a bony fish of the family Mugilidae, Class Actinopterygii (ray-finned fishes) and the Order Perciformes. The family consists of 17 genera and 80 species. Although, Chelon, Liza, Mugil and Valamugil. *Liza dumerilli* (grooved mullet), *L. grandisquamis* (large-scale mullet), *L. argentea* (flat-tail mullet) and *L. triscuspider* (stripped mullet) are said to be the most common members of the genus Liza. [24] reported on the aspects of *L. falcipinnis* from the Lagos lagoon, Nigeria. Mugilidae are cultured in many countries due to their high-quality flesh. According to [31], they are of great economic importance in tropical inland waters of West Africa and they play significant roles in the ecology of African freshwater. They are easily recognizable with their thick yet streamlined bodies, hard angled mouth, large, cycloid or faintly ctenoid scales, sub abdominal pelvic fin and two widely separated dorsal fin, the first containing only four spines [33]. They have no lateral line, pectoral fin is high on body

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and mouth is small terminal or inferior with pre-maxillae protractile, their teeth are small, feeble and could be hidden [31]. Body is elongated, cylindrical with broad flattened head with blunt snout (Figure 1). They are silvery in colour, often with 3 to 9 longitudinal streaks on the back, fins are hyaline and husky. The streamlined body of the mullet allows them to avoid numerous predators that attack their schools on the shallow inshore water. They spawn in the sea and then enter lagoon, estuaries and freshwater for feeding [19]. Length-weight relationship (LWR) shows that the average weight of fish at a given length by making use of a mathematical equation to show relationships between the two. Fish can attain either isometric or allometric growth [32]. Isometric growth indicates that both length and weight are increasing at the same rate. Allometric growth can be either positive or negative. Positive allometric implies increase in weight with increase in length. Negative allometric implies the fish becomes lighter as its length increases. However, LWR is assumed to be uniform for an entire fish stock in stock assessment studies [14]. Knowledge of the relationship between the length and weight of a given species is useful to transform the length structures obtained into the weights of fish captured and to monitor health status of a population. [4], opined that fluctuation in fish growth is a common phenomenon in tropical and subtropical waters because of environmental variations, spawning and dynamics of food composition.

Condition factor (CF) is an estimation of general well-being of fish as stated by [27] and is based on the hypothesis or assumption that heavier fish (at a given length) are in better condition than the lighter ones. The condition factor of 1.0 or greater indicates the good condition of fish while less than 1.0 shows bad condition [2]. It is a useful index for estimating growth rate and age and for assessing environmental quality and can be influenced by season, sex, type of food organism consumed by fish, age, and environmental conditions. The gonadosomatic index (GSI), is described as gonad mass as a percentage of total body weight and is widely used as a simple measure of the extent of reproductive investment, gonadal development and maturity of fish in relation to spawning [12,9]. Gonadosomatic index of fish increases with maturity and abruptly declines after spawning. GSI is particularly helpful in identifying season of spawning as the female gonads increase in size prior to spawning [18]. Study on reproductive biology of fish is essential for conservation and selecting fish candidates of aquaculture from the wild. Reproduction is an important physiological system that is crucial in the life cycle of fish. Fecundity is the number of ripened or vitellogenin eggs or oocytes in the female prior to the next spawning period and varies intra- and interspecifically. It is also stated that the number of eggs produced by fish in a spawning season is species-specific and varies with genetic characteristics, size, age, environmental factors and physiological conditions of the fish. For instance, large female fish in better condition tend to exhibit higher fecundity than those in poor condition. This information is useful in estimating spawning stock biomass and management [18].

In the study area, *Liza falcipinnis* is known to be abundant and this has been related to their feeding habits. The monthly incidence of occurrence of *L. falcipinnis* in canoe landings of artisanal fishermen in the Ojo axis of Badagry creek showed that it occurred in the lagoon on a year-round basis. However, there is not enough information on the species in the study area. This research is therefore geared towards reporting significant data on the species' condition factor, fish growth pattern, and reproductive biology (gonadosomatic index GSI) with the hope that this scientific information can be useful in the ecological, biological management and also biodiversity of the species. This information is needful for sustainable management of *Liza falcipinnis* in Ojo axis of Badagry creek, where it is caught in large numbers with unregulated fishing gears and methods. The major problem of this research is that adult sizes of the fish were rarely caught in Ojo lagoon. The specific objectives are to determine the species' growth pattern using Length- Weight relationship (LWR) of the Vonbertalanffy growth equation; length frequency of the year classes in the population using Petersen method; condition factor (K-Factor) i.e. condition of well-being of the species; the gonadosomatic index of the species (GSI) and sex ratio using the Chi-square (X^2).

2. Study Area

Ojo axis of Badagry creek is along the Badagry water system in the Northern area, this is shown in Figure 1 (marked X) in the map of the Lagos lagoon complex, which comprises of the Epe lagoon in the south; Lagos lagoon in the middle, Ologe lagoon and the Badagry creek in the north. The Ojo axis of the creek extends from Ojo Army Barracks down to ijanikin Local Government Area Headquarters, Lagos state. The samples were collected specifically within coordinates: 6°28N 3°11E and 6.467°N 3.183°E. [24] stated that Badagry creek is a long stretch of water body that runs parallel to the Atlantic Ocean in the south; it extends from Lake Nokue near Port-Novo to Apapa area of Lagos, and from there opens into the Ocean through the Lagos harbour. Fish species are highly diversed in the Ojo creek; examples are *Ethmalosa, Gobioides, Cynoglossus, Pomadasys, Pseudotolithus, Tilapia, Liza, Clarias, Selene, Macrobrachium and Callinectes.*

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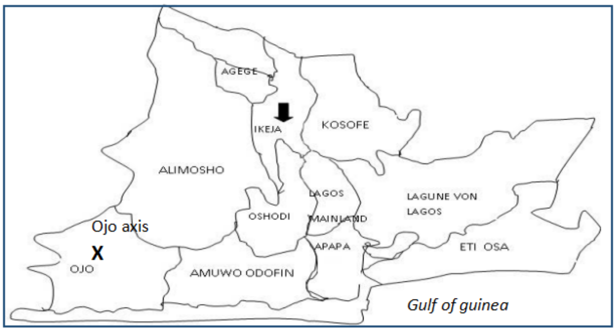

Figure 1. Map of the Lagos lagoon complex, showing the Ojo axis (marked X) of Badagry creek, Lagos, Nigeria

3. Material and Methods

3.1 Fish Sample Collection and Laboratory Analysis

Edible fishes were procured from the fishermen on the creek (Ojo) on a monthly basis from May, 2019 to March, 2020. The sampling gears used for fishing by the fishermen include baited long lines, cast nets and set gill net. A total of at least 1012 samples of *Liza falcipinnis* were collected for the analysis. The samples were transported in an ice chest to the Fisheries Laboratory at the Department of Fisheries, Lagos State University, Ojo, Lagos State for proper identification and examination. Fish identification was made to the lowest taxonomic level. Relative abundance of species was calculated by dividing number making up a species by the total number of fish sampled multiplied by 100%. The total and standard length of fish sampled were measured using measuring board graduated in cm. Range of the length frequency was determined and recorded. Weight was measured using a weighing balance. The average weight of these samples was used to estimate the number of individuals from the total catch for the week. The biometric data such as total length were taken to the nearest grams. Identification was done as following [3].

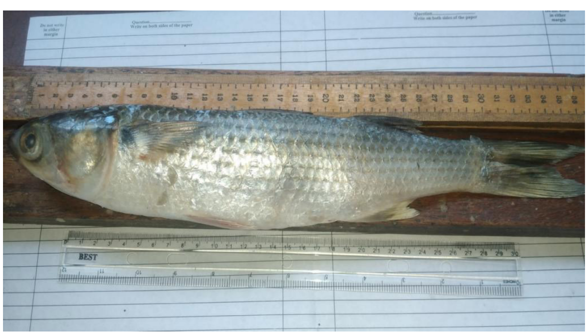

Figure 2. Sample of *Liza falcipinnis* (mullet) from Ojo axis of Badagry creek, Lagos, Nigeria

3.2 Length Weight Relationship and Length Frequency Analysis

The length weight relationships were obtained from the linear regression analysis

Intercept:a = $\left[\frac{\sum Y}{N} - \left(b.\ \frac{\sum X)}{n}\right)\right]$

The slope ('b') as: $b = \dfrac{\sum XY - \frac{(\sum X)(\sum Y)}{n}}{\sum X - \frac{(\sum X)2}{n}}$

And the correlation Coefficient ('r') as: $|r| = \dfrac{\left[\sum XY - \frac{(\sum X)(\sum Y)}{n}\right]}{\left[\sum X - \frac{(\sum X)2}{n}\right]\left[\sum Y2 - \frac{(\sum Y2)}{n}\right]}$

Where: X= Lengths of fish, Y= Weights of fish, and n= number of specimens.

The length-weight relationships for males and female specimens were obtained and a scattered diagram was drawn to determine the statistical relationships.

The relationship was expressed as: **W= a + bL.**

The same data was converted to logarithms and straight-line graph was drawn and the relative slope (b) was obtained from the relationship: $\mathbf{Log_{10}W = a + b\ log_{10}L}$.

3.3 Length-Frequency Method (Petersen Method)

The method currently in use for the analysis of length-frequency data; all finds their origin from the work of Petersen (Petersen methods). With this method, the assumptions were made as to the time interval separating the various peaks of one length frequency sample. These peaks were assumed to represent distinct age groups in a year class.

3.4 Condition Factor (K)

Fulton's condition factor (K) obtained for both sexes was expressed as:

$$K = 100W/L^3$$

Where W= weight of fish (g), L= Length of fish (mm). Therefore, the condition factor (K) was used to compare the condition, fatness or well- being of both sexes of the fish [22].

3.5 Sex Ratio

The differentia in sex distribution of the pollution of *Synodontis clarias* was determined from the separation of sexes into males and females. The chi-square technique was used where the observed (X^{2tab}) was measured against the chi-square calculated (X^{2cal}) as expressed below:

$$X^2 = (O - E)^2/E$$

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3.6 Gonadosomatic Index (GSI)

The gonadosomatic index (GSI) was determined or calculated based on the formula suggested by [22] which is expressed as:

$$\mathbf{GSI} = \frac{\mathbf{Gonad\ weight\ (g)\ x\ 100}}{\mathbf{Total\ body\ weight\ (g)}}$$

4. Results

4.1 Seasonal Abundance

Seasonal variations in number and weight are shown in Figure 4 for both sexes. Highest catches in the total number of fish occurred in June 2019; while the highest catches in weight occurred in February 2020 in the study area. However, Figure 5 showed the seasonal abundance in the population of female *Liza falcipinnis* from Ojo axis of Badagry creek. It reveals that the highest female catches in number were in October, December 2019, and February 2020. This thus coincides with peak of rainy season, while the highest peak of catches in weight was reported in February 2020. The male sex showed a different seasonal distribution. The male had the peak population in number in June 2019 and March 2020 with a corresponding highest catch in weight in the same month as shown in Figure 3. The population distribution in terms of catches was lowest from August to February 2020 for the males in term of weight and total number of fish.

4.2 Morphometric Analysis and Length Weight Relationships

The result of the monthly morphometric analysis, length weight relationship and condition factor of Liza falcipinnis from Ojo axis of Badagry creek from May, 2019 to March, 2020 are presented in Table 1. The mean length for combined sexes was between 15.9 cm (May, 2019) and 30.5 cm (Jan 2020). The mean weight was between 35.19 g (may, 2019) to 247.4 g (Feb, 2020). However, the intercept of the length weight relationships was positive through-out the year, values were between 8.9 cm to 17.6 cm. The slope of the graph was equally all positive which suggests positive allormetrism, the lowest b value was 0.02 and the highest value was 0.1, this is shown in Figure 3, 4 and 5. The correlation coefficients (r) were generally high from 0.46 to 0.8. The mean length for female was between 15.89 cm (May 2019) to 31.74 cm (Jan 2020). The mean weight was between 34.29 g (May, 2019) and 296.09 g (Feb, 2020). The length weight relationship for female was positive through-out the year. Values were between 7.64 cm and 18.20 cm. The slope of the graph was also positive which showed an allometric growth pattern. The lowest b value was 0.02 and the highest was 0.11 (Table 1). The correlation coefficient (r) was generally high from 0.55 to 0.96. The mean length for male was between 15.92 cm (May) and 28.42 (November). The mean weight was between 35.7 g (May, 2019) and 161.44 g (Jan 2020) (Table 1).

Table 1. Changes in Seasonal Abundance of *Liza falcipinnis* in Ojo axis of Badagry Creek, Lagos

Month	Combine sexes				Females				Males			
	No of fish	% No of fish	Total Wt (g)	% Total Wt	No. of fish	% No of fish	Total Wt (g)	% Total Wt	No of fish	% No of fish	Total Wt (g)	% Total Wt
May	74	7.31	2604.2	2.2	27	5.4	925.9	1.3	47	9.2	1678.1	3.6
June	146	14.4	10163.9	8.6	33	6.6	3156.7	4.8	113	22.0	7007.8	15.2
July	119	11.8	9698.1	8.2	35	7.0	4448.5	6.2	84	16.2	5249.6	11.4
August	96	9.5	11041.1	9.3	45	9.0	6182.8	8.8	51	9.9	4858.3	10.5
September	91	9.0	9361.4	8.0	51	10.2	5347.6	7.4	40	7.9	4091.9	8.8
October	94	9.3	12227.8	10.3	60	12.2	7900.6	10.9	34	6.6	4327.1	9.4
November	54	5.3	8122.7	6.8	38	7.6	5598.0	7.7	16	3.1	2524.7	5.5
December	88	8.7	12119.5	10.2	62	12.4	8579.0	11.9	26	5.1	3540.5	7.7
January	73	7.2	11192.3	9.5	51	10.2	7802.1	10.8	22	4.1	3390.2	7.4
February	86	8.5	21275.8	18.0	61	12.2	18061.5	25.0	25	4.9	3214.3	6.9
March	91	9.0	10361.88	8.8	36	7.2	4133.7	5.7	55	10.9	6226.1	13.5

Note: Wt = fish weight in grams.

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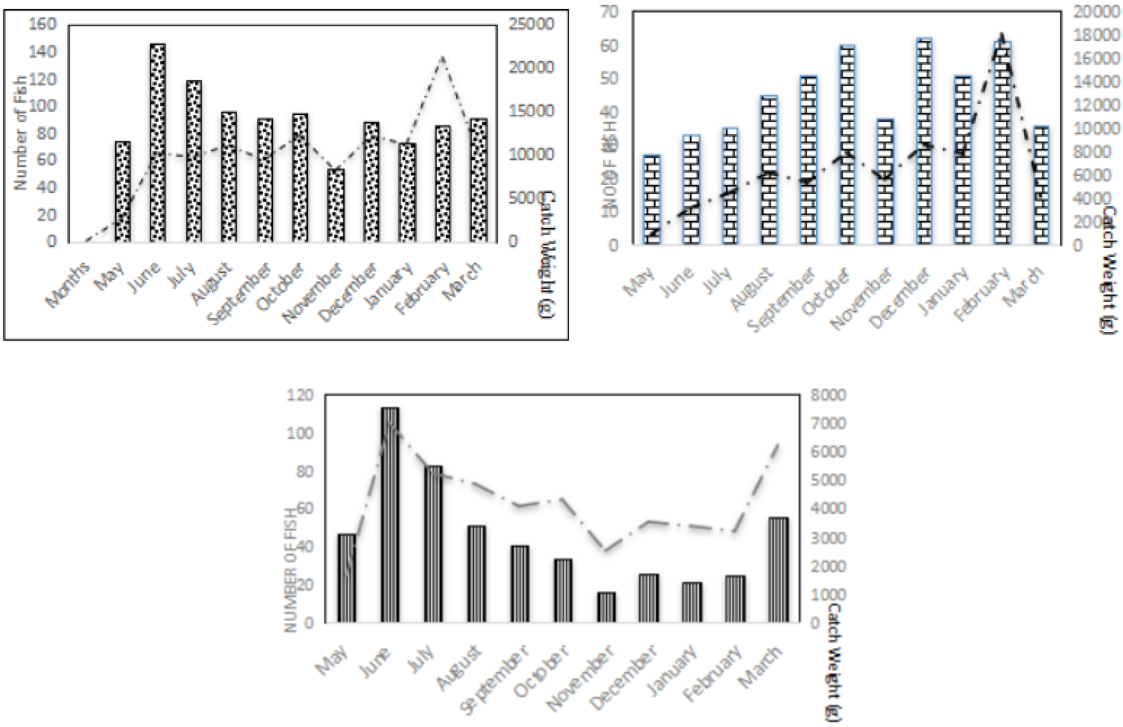

Figure 3. Changes in Seasonal abundance of (1) Combine sex, (2) Females and (3) Males of Liza falcipinnis from Ojo axis of Badagry creek, Lagos-Nigeria.

Table 2. Morphometric measurements in *Liza falcipinnis* from Ojo axis of Badagry creek, Nigeria

Morphometric measurements (mm)L	Combined sex(n = 1012)			Males(n = 513)			Females(n = 499)		
	Range		Mean±SD	Range		Mean±SD	Range		Mean±SD
	Min	Max		Min	Max		Min	Max	
Eye diameter (ED)	0.5	2.5	1.23±0.1	0.7	2.6	1.13±0.22	0.5	2.5	1.34±0.68
Head length (HL)	2.1	12	4.63±0.5	2.1	10.4	4.25±0.94	2.5	12	5.03±1.23
Head depth (HD)	1.7	8.1	3.56±0.4	1.7	7.7	3.27±0.75	2.0	8.1	3.85±0.86
Body depth (BD)	2.5	11.7	4.68±0.5	2.5	9.7	4.35±0.87	2.6	11.7	5.02±1.1
Total length (TL)	2.6	233.3	24.95±2.8	12.5	44.4	21.78±4.88	2.6	233.3	26.19±10.6
Body weight (g)	9.23	1006	121.7±55.1	9.23	700	107.1±40.6	15.6	1006	134.6±62.9

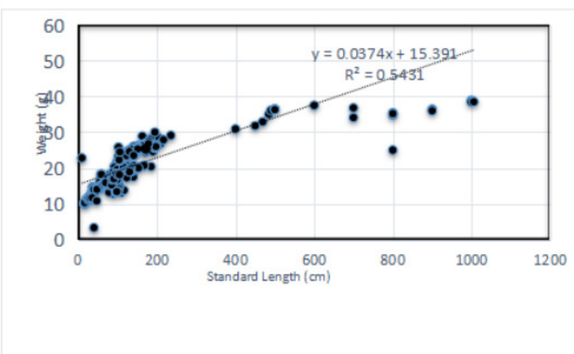

Figure 4. Standard Length-Weight relationship in Combined sexes of Liza falzipinnis from Ojo axis of Badagry creek, Lagos Nigeria

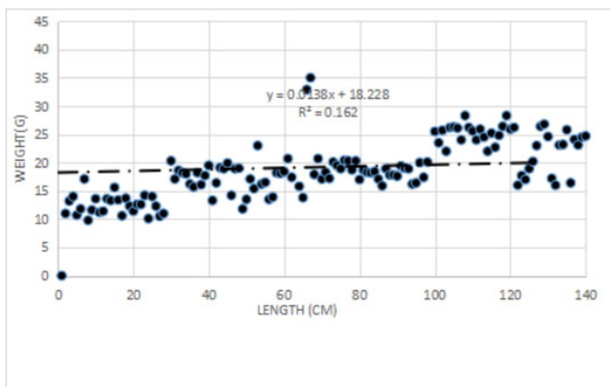

Figure 5. Length-Weight Relationship of Female Liza Falzipinnis from Ojo axis of Badagry creek

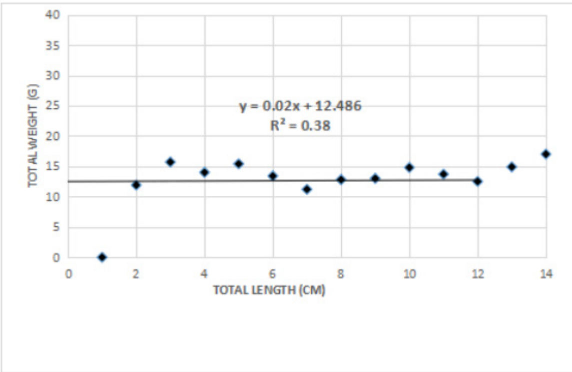

Figure 6. Length-Weight Relationship of Male Liza Falzipinnis from Ojo axis of Badagry creek

4.3 Length Frequency Analysis

Fish total length measurements were categorized into 21 modal classes for combined sexes which showed a bi - modal distribution of Liza falcipinnis from Ojo axis of Badagry creek. The cohort were from 1.9 cm to 39.9 cm (TL). The modal length was from 17.19 cm to 19 cm and 22.8 cm to 24.7 cm for combined sexes with frequency of 17.8% of the population and 17.5%. The distribution of species in the population skewed more to the right, this means that they were larger fish species in the sampled population. There was large number of fish between 17.1 cm and 19 cm and between 22.8 cm to 24.7 cm (TL). Two age groups (Age 1 and 2) were obtained from the sampled population which was ascertained from the modal distribution of length frequency histogram in Figure 7[A] for combined sex of *Liza falcipinnis* from Ojo axis of Badagry creek Lagos Nigeria. Total length measurement for female *Liza falcipinnis* were categorized into 18 modal classes as shown in Figure 7[B]. The cohort were from 2.2 cm to 39.6 cm (TL). Modal length was from 24.2 cm to 26.4 cm with frequency of 14.3% of the population. There were large numbers of fish between 24.2 cm and 26.4 cm. Two age groups (Age 1 and 2) were also obtained from the sampled population through the length frequency histogram (Figure 7). The total length measurement for male *Liza falcipinnis* from Ojo axis of Badagry creek were categorized into 21 modal classes (Figure 7C). The cohort were from 0.1 cm to 46.2 cm. Modal lengths were from 19.8 cm to 22 cm with frequency of 9.1% of the population. There was a large number of fish between 17.6 cm and 22 cm. Two age group from the sampled population were observed in length frequency histogram.

4.4 Condition Factor

The condition factor of the combined sex is shown and elucidated in Table 2 and it showed that the fish were not in good condition with the lowest condition factor of 0.68 (Dec., 2019) while the highest condition was 0.85 (June, 2020). These values showed that the female *Liza falcipinnis* from Ojo axis of Badagry creek were in better condition. The females gained more weight than the males. The females had the best condition in February (0.83) and the poorest condition in October (0.69), the males had a better relative increase of condition which was observed in June 2019 and low condition in November 2019 (0.68).

4.5 Sex Ratio

Samples of *Liza falcipinnis* from Ojo axis of Badagry creek showed differences in the distribution in term of sexual dimorphism (distribution of male and female species). This is shown in Table 4. Sexual differences were observed throughout the year. The males were numerically more dominant than the female ($P<0.05$) in May

Table 3. Summary of monthly morphometric analysis, Length-Weight Relationship and condition factors of *Liza falcipinnis* from Ojo axis of Badagry Creek, Lagos. (2019 - 2020)

Months	Combine sexes						Females						Males					
	Mean length	Mean weight	a	b	r^2	k	Mean length	Mean weight	a	b	r^2	k	Mean length	Mean weight	a	b	r^2	K
May	15.91	35.19	8.92	0.1	0.86	0.83	15.89	34.29	8.68	0.11	0.96	0.81	15.92	35.7	9.05	0.1	0.82	0.83
June	19.83	69.62	10.52	0.07	0.77	0.85	22.72	95.64	11.25	0.06	0.55	0,79	18.98	62.02	10.38	0.07	0.79	0.86
July	20.73	82.19	11.71	0.05	0.85	0.81	24.67	127.10	13.73	0.04	0.91	0.79	19.08	63.25	11.1	0.06	0.81	0.83
August	24.60	115.01	8.97	0.1	0.85	0.76	26.56	137.4	11.52	0.09	0.83	0.73	22.87	95.26	5.72	0.14	0.82	0.8
September	23.37	102.87	8.13	0.1	0.71	0.81	23.64	104.86	7.64	0.11	0.73	0.79	22.97	99.8	9.13	0.1	0.68	0.82
October	26.21	130.08	10.48	0.1	0.77	0.70	26.28	131.68	10.96	0.09	0.72	0.69	26.08	127.27	9.82	0.1	0.85	0.71
November	27.64	150.42	17.59	0.05	0.60	0.72	27.32	147.32	17.05	0.05	0.83	0.73	28.42	157.79	19.87	0.03	0.16	0.69
December	27.19	137.72	16.52	0.06	0.89	0.68	27.21	138.37	16.58	0.06	0.87	0.68	27.15	136.17	16.44	0.06	0.93	0.68
January	30.54	155.45	17.60	0.04	0.66	0.70	31.74	152.98	17.94	0.04	0.68	0.69	27.63	161.44	16.59	0.05	0.64	0.74
February	28.04	247.39	16.98	0.02	0.78	0.82	29.95	296.09	18.20	0.02	0.79	0.83	23.39	128.57	13.61	0.04	0.85	0.81
March	24.48	112.63	11.34	0.07	0.46	0.77	24.34	114.88	10.97	0.07	0.65	0.79	24.56	111.18	11.46	0.08	0.42	0.75

Note: LWR = length-weight relationship, a = intercept, b = slope of graph, r = correlation coefficient, K-factor = condition factor, mean length in cm and mean weight in grams

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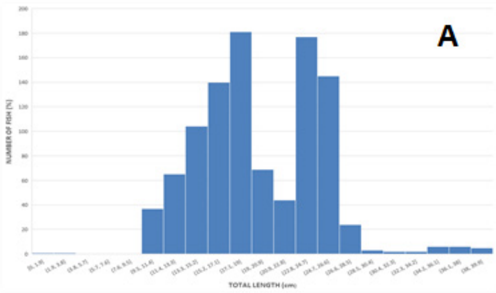
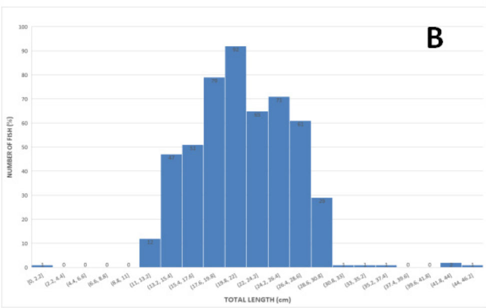
(2.0: 1.0), June (3.4: 1.0), July (2.4: 1.0), August (1.1: 1.0), 2019 and march (1.5: 1.0), 2020. The monthly sex ratio analysis (Male: Female) is in favour of the females; in September (1:1.3), October (1:1.8), November (1:2.4), December (1:2.4), January (1:2.3) and February (1:2.4). However, the Chi-square analysis (Table 4) revealed a rejection of the null hypothesis [there were no differences in sex distribution] (P<0.05), because the Chi calculated (X_{cal}) values were significantly higher than Chi tabulated (X_{tab}) for most part of the period of study; except for the months of August (0.38), and September (1.33), as against the Chi $_{tab}$ of 3.841.





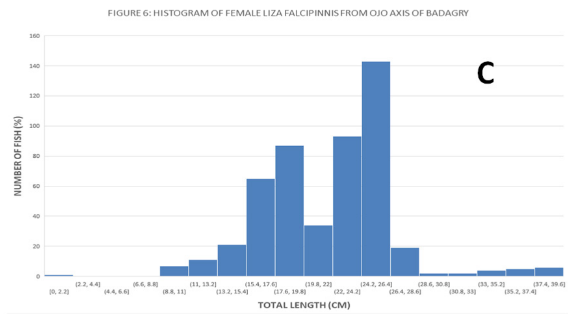


Figure 7. Length frequency distribution (Histogram) of Combined sexes [A], male [B] and Females [C]; Liza falcipinnis from Ojo axis of Badagry creek, Lagos, Nigeria.

4.6 Gonadosomatic Index (GSI) and Spawning Period

The monthly gonadosomatic index (GSI) values for female *Liza falcipinnis* from Ojo axis of Badagry creek is shown in Table 5. GSI values varied from 0.73 - 6.16 (2.3±2.79) in May, 0.17 - 10.12 (1.75±5.35) in June, 0.1 - 3.84 (1.27±1.91) in July, 0.24 - 17.77 (2.88±9.45) in August, 0.19 - 1.81 (0.92±0.81) in September, 0.4 - 4.78 (1.56±2.27) in October, 0.6 - 5.39 (2.05±2.46) in November, 0.78 - 8.24 (3.27±3.8) in December, 2019; 0.13 - 8.6 (2.18±4.42) in January, 0.14 - 9.97 (2.15+5.19) in February, and 0.47 - 10.03 (3.28±4.91) in March, 2020 respectively. GSI value for the female were found to vary with time (monthly) and the highest index observed was in August, 2019 (17.77) with mean of 2.88±0.75 and the lowest in July, 2019 (0.1) with mean of 1.27±0.01.

Table 4. Sex distribution, ratio and Chi-square analysis of *Liza falcipinnis* in the monthly samples from Ojo axis of Badagry creek, Lagos

Months	No. of fish Combined sexes	E	No. of males (O)	No. of females (O)	Sex ratio M:F	$\frac{(O-E)^2}{E}$ male	$\frac{(O-E)^2}{E}$ Female	X^2_{Cal}	X^2_{tab} at [P<0.05
May	74	37	47	27	2.0:1.0	2.70	2.70	5.41	3.841
June	146	73	113	33	3.4:1.0	21.92	21.92	43.84	3.841
July	119	59.5	84	35	2.4:1.0	10.09	10.09	20.18	3.841
August	96	48	51	45	1.1:1.0	0.19	0.19	0.38	3.841
September	91	45.5	40	51	1.0:1.3	0.66	0.66	1.33	3.841
October	94	47	34	60	1.0:1.8	3.60	3.60	7.19	3.841
November	54	27	16	38	1.0:2.4	4.48	4.48	8.96	3.841
December	88	44	26	62	1.0:2.4	7.36	7.36	14.73	3.841
January	73	36.5	22	51	1.0:2.3	5.76	5.76	11.52	3.841
February	86	43	25	61	1.0:2.4	7.53	7.53	15.07	3.841
March	91	45.5	55	36	1.5:1.0	1.98	1.98	3.97	3.841

Note: E = expected, O = observed, X^2 = Chi-square, X^2_{tab} = tabulated chi square < 0.05 confidence limit and X^2_{cal} = Chi-square calculated

Table 5. Monthly GSI for female Liza falcipinnis in Ojo axis Badagry Creek, Lagos

Months	MIN GSI	MAX GSI	MEAN GSI+SD
May	0.73	6.16	2.3±2.79
June	0.17	10.12	1.75±5.35
July	0.1	3.84	1.27±1.91
August	0.24	17.77	2.88±9.45
September	0.19	1.81	0.92±0.81
October	0.4	4.78	1.56±2.27
November	0.6	5.39	2.05±2.46
December	0.78	8.24	3.27±3.8
January	0.13	8.6	2.18±4.42
February	0.14	9.97	2.15±5.19
March	0.47	10.03	3.28±4.91

5. Discussion

Relative high abundance of *Liza falcipinnis* in Ojo axis of Badagry creek was observed in the study, during the study period. Although, the total number caught for each month varied (as shown in Table 1) and this can be related to seasonal changes, fishing activities, recruitment, availability of food and changes in the behaviour of the fish. This opinion was shared by [28] who worked on the biology of two species of catfishes: *Synodontis schall* and *Synodontis nigrita* from Queue River, Benin. They reported that high species yield in catches during April and May corresponds to the beginning of rainy season, when food availability is highest due to flood introducing nutrients and mixing of water by rapid currents. Such ecological situations are favourable to fishes and may cause them to venture out of their hidden crevices making them vulnerable for fishing. The current study reveals that the highest catches by number was in June and July 2019. This result corresponds with the above result as reviewed. Increase in fish abundance due to the combination of physiochemical properties and presence of food items has been reported by [11]. However, catches in weight was contrasted to catches in number, which showed that there is overfishing in the study area.

Morphometric and meristic characters were studied on *Liza falcipinnis*, 6 morphometrics and 4 meristic characters were examined for each sex. It was compared to find out the phenotypic differences in the population (Table 2). The morphometric measurements between male and female *Liza falcipinnis* showed some slight variations, but not sufficient to discriminate between male and female sexes. The male and female individuals showed similarities with each other with respect to all morphological characteristics. The variation between both sexes revealed that the female exhibited higher measurement values than that of the male which was supported by [24] who observed similar results. The present study revealed that though some variations were observed in each morphometric and meristic characters between sexes, but such variations or differences were insignificant ($p<0.05$). Therefore, this indicated a negligible effect of sex on variations in the morphometric and meristic characters. This report agrees with [34]. The above data indicates that the female sex is phenotypically larger than the male. [34] and [8] reported that both meristic and morphometric character of fish maybe influenced by certain environmental factors e.g. turbidity, food availability, temperature, therefore variation showed in the present study on morphological characters among male and female of *Liza falcipinnis* might be as a result of differences in the environmental condition of the habitat, availability of food, sample size, sex condition, sexual maturity; all these may lead to produce the phenotypic differences between the male and female sexes of species as previously corroborated by some workers including [29], [17] and [13].

Growth of fish can be described as either allometric or isometric depending on the value of 'b' (regression coefficient). The b value of *Liza falcipinnis* from Ojo axis Badagry creek were 0.04, 0.01 and 0.02 for combined, male, and female sexes respectively. This indicated that the fish exhibited a negative allometric growth pattern which shows that the species under this study became thinner as they grew longer. The results also showed that the species are in poor condition and were not robust enough, relative to its length. Similarly, to [15] who reported a weak correlation coefficient (r) for Australian mullet with $r = 0.87$ for males and 0.86 for females. In this current study, the r^2 values were 0.54 for combined sexes, 0.16 for females and 0.38 for males, showing a strong relationship between total length and body weight measurements of the fish. Though, there was increase in total length with corresponding increase in bodyweight; the general condition of the species in the study area are considered slightly weak. Length weight relationship are useful tools for fisheries research because they allow the conversion of growth in length equation to growth in weight for use in stock assessment model, and allows for the estimation of biomass from length observation, Also, the estimate of the condition of the fish and are useful tools for regional comparism of life histories of certain species [25].

The condition factor of fish is regarded as the fitness or relative well-being of the fish. It indicates the general metabolism of fish. These values indicated poor well-being of the assessed fish. [7] related low condition to the period when accumulated fat is used for spawning, while high values indicate a period of increase rate of feeding followed by a gradual increase in accumulated fat, which suggest preparation for a new reproductive period. This

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result is similar to the report of [24] on the same species from Badagry creek. He reported condition value of 0.0079, 0.0087, 0.0097 for immature, males, and females respectively. He therefore suggested that the reason for low condition of *Liza falcipinnis* from Badagry creek is due to ecological and environmental factors and also an indication of how well the species is in this water body. The value for condition factor in this study varied slightly between the male and female fish. The slight variation could be attributed to food availability, gonad development and gender of fish [30,16].

The length frequency distribution of all the species were not having equal interval due to the presence of small sized fish in the assessed population. The length frequency distribution graph (Figure 7A, 7B and 7C) indicated that the *Liza falcipinnis* from Ojo axis of Badagry creek were dominated by two modal lengths or year classes or age groups/cohorts (representing ages 1 and 2). For combined sexes, the sampled population was dominated by fish of length 24.2 - 26.4 cm, while the male population was dominated by fish of length 19.6 - 22 cm. This observation implies that the females have bigger dominant sizes within the population. Gonadosomatic index is one of the essential parameters in studying the reproductive biology of the fish. It's used to describe the gonadal stage or development/ spawning stage/level of ripeness of the ovary in the different sexes of fish. In this study, the Gonadosomatic Index (GSI) for female *Liza falcipinnis* from Ojo axis of Badagry creek was studied between May 2019 to March, 2020. The GSI was highest in August 2019 with 17.77% (as shown in Figure 3) which indicated the peak of spawning in this species in the study area. Figure 3 shows that gonadal maturation actually began in June (2019) and was completed in August (2019) which coincides with the peak period of rain season. It decreased thereafter from September (2019) to November (2019) showing a period of sexual rest. [10] reported that gonadal maturity began in September (dry season) and was completed in November (rain season) for the same species from two lagoons in Cote D-Ivoire and this coincide with flood season of the area and thus creates an ideal condition for the survival of larval and fingerlings due to abundance of food. During flood season nutrients are drained by the rich run-off in organic matter, the decomposition of organic matter enriches the environment in mineral salts which will lead to proliferation of algae according to [20]. The availability of food during this period is utilized by the larvae therefore they do not have to travel long distance in search of food as opined by [26].

Sexual dimorphism or unbalanced sex ratio in the mullet has been observed by several authors: [24,1,5] amongst others. The prevalence of one of the sexes is a relatively frequent phenomenon in many teleosts and this could come from differential growth according to sex. In the current study, the males were dominant in May, June, July, August, 2019, and March, 2020. (2:1, 3.4:1, 2.4:1, 1.1:1, and 1.5:1 respectively). The variation was an indication that sex was in favour of the males during this period. Sex ratio that favoured the females may account for its reproductive success in Ojo axis of Badagry creek. The female sex was dominant in September, October, November, December, 2019, January and February, 2020. (1:1.3, 1:1.8, 1:2.4, 1:2.4, 1:2.3, 1:2.4 male: female respectively). [10] also reported the dominance of female *Liza falcipinnis* from Ebrie and Grand-Lahou lagoon. He stated that the reason may be due to higher mortality of the male at larva stage and less accessibility of the male due to ethological differences related to sex. According to [6] and [17] the female Mugilidae reaches sexual maturity at larger size than the male.

6. Conclusions

The implication of the results is that fish abundance (by number) in June and July, 2019 prompted more fishing activities leading to recruitment overfishing and growth overfishing. Sexual differences in relation to seasonal abundance were clearly observed and highlighted.

The female sex is phenotypically larger than the male. The report thus concludes that both meristic and morphometric characters of fish maybe influenced by certain environmental factors.

The growth of the species was negatively allormetric. There was increase in total length with corresponding increase in bodyweight; but the general condition of the species in the study area are considered slightly weak. The results are essential because they allow the conversion of growth in length equation to growth in weight for use in stock assessment model.

The values of condition factor indicate poor well-being of the assessed fish. The males were dominant in May, June, July, August, 2019, and March, 2020.

The sex variation showed that sex was in favour of the males during some period. Sex ratio favoured the females during reproductive periods which coincides with the months of September, October, November, December, 2019, January and February, 2020 in the study area.

The GSI was the highest in August 2019 with 17.77%. Gonadal maturation actually began in June (2019) and was completed in August (2019) which coincides with the peak period of rain season.

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ARTICLE

Status stock and Sustainable Management Measures for Moroccan Sardines

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ABSTRACT

This article summarizes the state of stocks of sardine, *sardina pilchardus* in Moroccan waters at the end of 2016 and 2018. These stocks varies according to the region,They are now in a sustainable exploitation situation: Atlantic sardine, but also stocks that have reached or are still in over-exploitation levels: Mediterranean sardine. The fishing pressure exerted on the sardine stock exceeds the optimal level by 40%. Due to the degradation of the fragile marine environment of the Mediterranean region, generated by pollution of various origins, the overexploitation of juveniles in the coastal strip, non-responsible practices and the use of non-fishing gear selective, it is imperative to take the necessary measures to protect the marine environment and ensure rational and sustainable exploitation of the resource. (High commission plan 2006 report).

1. Introduction

The northwest African upwelling system of Morocco, is the most productive in the world, in terms of primary productivity. This productivity results in large fish biomass mainly dominated by small pelagic fish, which are the main exploited living resources of the region. In a context of shared management by several countries of the region's fishery resources, understanding the factors that control the spatial distribution of small pelagic popula-

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tions and the evolution of their abundance is crucial for fisheries and the region's socio-economic development.

Morocco has two maritime frontages of approximately 3,500 km of coastline, supported by an Exclusive Economic Zone1 (EEZ) of 200 nautical miles in the Atlantic. These advantages, combined with the existence of a upwelling2 zone, considered among the most important in the world, make the Moroccan coast one of the most fish-rich zones, with an annual production potential that exceeds 1.5 million tons of fish. A relatively large specific diversity characterizes this reservoir of fishery wealth. The fishing sector represents between 2% and 3% of gross domestic product (GDP) and generates around 170,000 direct jobs and 500,000 other indirect ones while providing sources of income for around 3 million people [1]. In 2015, national fishery production exceeded 1.35 million tons (worth 10.8 billion dirhams), mainly small pelagic (84% in volume and 25% in value). Thanks to this production, Morocco ranks 17th among producer countries (capture fishing) and first on the African continent [2]. This production is mainly generated by a fishing fleet of coastal and artisanal vessels (56% in volume; 54% in value) and deep-sea vessels (34% in volume; 44% in value). However, despite the importance of national fishery production, Moroccans' consumption of fishery products remains limited to levels below the world average (13.3 kg/inhabitant against 19.3 kg/inhabitant on the scale in 2012). Morocco has set itself the strategic objective, within the "Halieutis" Plan framework, of bringing this average to 16 kg/inhabitant/year around 2020. Starting from producers' objective aiming to maximize their income and facing demand for fishery products that continues to grow, especially in a context of increasingly imposed globalization, the fishery sector has become particularly dependent on the rest of the world and other sectors of the economy. This strong dependence on the rest of the world places the fishing sector in a situation of vulnerability in the face of various hazards in the international economic environment.

The availability of fishery resources is one of the factors driving the dynamics of the fishery production system. This resource is dynamic in nature and constantly interacts with the bio-physicochemical system, characterizing its natural environment and the socio-economic and regulatory subsystems in which fishing activities are carried out. If the socio-economic conditions are favorable, the abundance of the exploited resource can potentially lead to fishing efforts. On the other hand, the increase in the latter beyond biologically sustainable limits can ultimately lead to a decrease in the availability of resources, thus affecting the balance between supply, demand and price of fish.

The sustainability of fishery resources will only be ensured through management systems that can adapt fishing pressure to the optimal level of stocks. The main control variable for this is fishing effort. The context and fishery issues have changed a lot, going from questions of prospecting and development of new fisheries to issues of biodiversity conservation, conservation in the face of over-exploitation, development, understanding of the effects of climate change or security marine

2. Fluctuations in Small Pelagic

The environnemet factors influence the distribution and fisheries abundance. This is the case for small pelagic fish, which are essential elements of marine ecosystems due to their intermediate food web position and large biomass. In upwelling ecosystems, the total biomass of fish is generally dominated by small pelagic, often a species of anchovy and/or a species of sardine or sardinella. We speak of ecosystems structured in "wasp-waist" [3,4], because of the small number of small pelagic species that constitute this intermediate trophic level. In this case, control of the trophic chain would be carried out by the intermediate link, the small pelagic. Thus, this intermediate-level will play a central role in the structure and the dynamics of the ecosystem, both by "top-down" type control (control of upper predators on the lower trophic links) on the plankton which it feeds and by bottom-up control on the many marine predators that consume them" [5]. Fluctuations in the abundance of pelagic fish stocks reflect significant changes in structure and functioning in upwelling ecosystems. Significant mortalities have been observed at higher trophic levels (birds, marine mammals, large predatory fish) in response to the decrease in the abundance of their prey.

Pelagic resources consist mainly of sardines, mackerel, anchovies, horse mackerel and tuna. These highly displaced and unstable resources experience more or less significant fluctuations in their abundance and distribution. The southern area of the Kingdom has known, in recent years, variations in their abundance and their composition by species.

Studying the effects of environmental change on fish populations, especially sardines, is complicated because environmental factors can affect various processes at different levels of biological organization" [6-9]. Fish has complex life cycles, including several different life stages (egg, larva, juvenile and adult), each of which can be affected in different ways by environmental changes. In fish populations, changes induced by changes in the environment

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can result from four mechanisms, often linked together: (i) a physiological response to changes in environmental parameters, such as temperature, (ii) a response behavioral, for example, by avoiding unfavorable conditions and displacement to new more favorable habitats, (iii) population dynamics, resulting from changes in the balance between mortality, growth and reproduction rates, (iv) productivity changes and/or trophic interactions in the ecosystem. In addition, (v) commercial exploitation greatly affects the abundance and distribution of fish and can interact with the effects of environmental change.

3. Sardines are an Important but Unstable Resource

World production of small pelagic represents around 39 million tons, or more than a third of the catches total, making small pelagic the most fished species group in the world (FAO). Over the past 60 years, catches have largely evolved according to variations in the resource. Small pelagic constitute the largest group of species targeted by the "milling fishery," whose catches are intended to manufacture fish meal and fish oils, mainly consumed by the aquaculture sector. With the development of intensive aquaculture to meet ever-increasing needs, small pelagic are diverted from their primary vocation to feed the poorest populations directly. In many countries of the world, and particularly in developing countries, small pelagic are an important source of protein and nutrients at affordable prices. These small pelagic fish thus occupy an important weight in the food and the world economy.

Instability is one of the major characteristics of small pelagic resources. Significant changes (by a factor of 1000) in abundance over a few decades are characteristic in small pelagic. Long-term alternations of dominant species are observed in most upwelling ecosystems, such as the alternation between sardines and anchovies in the Humboldt, Benguela and Kuroshio currents off Japan" [10]. The scientific community widely accepts that this high variability is caused by the synergy of different factors, including main overfishing and environmental conditions. The biological characteristics of small pelagic (short lifespan, high fertility, high natural mortality rate, dependence of plankton for their food) make them very sensitive to environmental forcing" [11,12]. In addition, because they are very mobile and good swimmers, pelagic fish can react quickly to changes in their environment. Small pelagic have a so-called "r" reproduction strategy (favoring a high growth rate) and can potentially double their populations within a few months, the age of first reproduction generally being between 6 and 18 months" [13]. Finally, their gregarious behavior facilitates their detection, and their catches contribute to their variability in abundance. Also, several stocks of small pelagic have suffered historical collapses, such as anchovies in Peru in 1972, sardines in South Africa between 1965 - 1966 " [14] and in Namibia between 1970 - 1971" [15].

The small pelagic resources, consisting of fish species on the surface or between the two water's layers (Sardine, Mackerel, Horse mackerel, Anchovies and sardinella), represent the main fishery potential of the Moroccan EEZ. Small pelagic fishing occupies an important place in the fishing sector in Morocco due to the size and the dynamism of the fleet which practices it, the quantities sold in the various sectors supplied with the products of this fishing and the number of 'direct and indirect jobs generated. Fishing for small pelagic extends across the entire Moroccan, Atlantic and Mediterranean continental shelf. The national fleet mainly leads it from different ports in the Kingdom and a foreign fleet operating under charter or fishing agreements. The fishery for small pelagic has developed along the Moroccan Mediterranean and Atlantic coast with a historic shift in the fishing area to the south at the Atlantic coast. Indeed, after exploitation of the northern sardine stock (Tangier-El Jadida) during the 1930s, fishing developed further south and the port of Safi became the first sardinian port during the 1970s. Then, 80, with the opening of Tan-Tan, Laâyoune and that of Tarfaya, the fishery moved further south, making the Sidi Ifni - Cap Boujdour area (area B) the main area of activity of the Moroccan sardine fleet. This development was reflected, notably from the 1990s, by a change in the evolution of landings, with a decrease in sardine catches in the North zone and the Safi-Sidi Ifni zone (zone A) and a continuous increase in sardine catch in zone B. The increase in sardine catches in zone B was accompanied by a change in the destination of production; the by-product industry absorbed the large share of landings, intended before the 1990s mainly for canned.

South of Cap Boujdour (zone C), an area historically exploited by a foreign fleet, the national small pelagic fishery began during the 1980s, with large-scale purse seiners (Thona type fishing) and from the 1990s with a coastal sardine fleet. This development of activity in zone C is supported by the opening of the port of Dakhla in 2001 and by the arrival of modern vessels which have added to the traditional purse seiners and have supported the development of the freezing sector. In addition, authorizations to charter foreign vessels (freezer pelagic trawlers, purse seiners and pelagic trawlers RSW type) were granted, from 1997 to operators of the Dakhla and Laayoune oc-

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topus freezing sector, as part of the program assistance in the conversion of excess processing overcapacity in this sector and also in the context of the development of the national small pelagic fishery in this area. Artisanal fishing activity has also emerged since 2008; this fishing is practiced by boats that operate from fishing sites in the region on mackerel, generally during the closed periods of octopus fishing.

Potentials currently offered for small pelagic species are available in the area south of Cap Bojdour and are variable depending on stocks. Certain populations (sardinella, mackerel, horse mackerel) form part of the straddling stocks exploited in the Moroccan EEZ and in the EEZs of the other countries of the Northwest African region. Sardines remain the dominant species in Morocco, while the availability of other species varies from one area to another and from year to year.

Sardine, the dominant pelagic species in upwelling ecosystems

The Moroccan Atlantic ecosystems are characterized by upwelling that promotes nutrient enrichment of the coastal strip, making these ecosystems very productive areas that support the most abundant fisheries in the world. In fact, despite a relatively modest area of less than 3% of the surface of the oceans, these regions concentrate a significant part of the fishing volume, representing 40% of the world catches of marine species" [5,10]. However, these upwelling ecosystems are very dynamic and show high variability at all spatial and temporal scales. Small pelagic fish are dominant in biomass in these ecosystems, mainly sardine and anchovy species, whose population dynamics are often linked to the very high physical variability of upwelling. Understanding the mechanisms linking environmental fluctuations to the recruitment of these species is one of the major challenges for fisheries in these regions.

A striking example is the large-scale fluctuations in sardines and anchovies observed in the main upwelling zones of the world" [16-18]. When one species has high biomass, the other species have relatively low biomass and vice versa. Changes in species biomass are generally accompanied by an expansion and/or contraction of their distribution areas" [19,20]. However, there is no general theory yet, shifts in ecosystem shifts [21]. That has occurred in response to climate change have been suggested as the main cause of fluctuations in sardines and anchovies" [22,23]. Many studies have suggested that these regime changes are associated with structural changes in the ecosystem (temperature, wind, upwelling but also the size of plankton particles), leading to favorable environmental conditions for a species rather than '' another" [18,19,24]. This is the case for the Peruvian anchovy (Engraulisringens), characterized in the 1960s by very large landings reaching 13 million tons in 1970, which collapsed during the 1970s and 1980s. Since the early 1990s, landings of anchovies from Peru have resumed and have hovered around 7 million tonnes, with a drop observed in recent years. In parallel, catches of Chilean sardinops (Sardinopssagax) have exploded in 15 years (1978-1992), reaching 10 million tons per year. Since 1992, landings have almost disappeared" [25]. The causes of large variations in the biomass of small pelagic fish, whether mainly due to natural variability (due to environmental changes and/or interactions between species), exploitation, or both, are still long-discussed [10,20].

4. Canary Upwelling

The Canary Islands' upwelling is located along the northwest coast of Africa, from Gibraltar (36°N) to southern Senegal (10°N) and runs along the coasts of Morocco, Mauritania, Gambia and Senegal. It results in a general surface current running along the coast from north to south. In this region, three upwelling zones have been described [26,27]. Upwelling has a strong seasonality between 11 ° N and 21 ° N and between 26 ° N and 35 ° N, and remains intense all year round between 20 ° N and 26 ° N. At high latitudes (26 ° N-35 ° N), the intensity of upwelling is low and intensifies in summer and autumn and weakens in winter and spring. At low latitudes (11 ° N-21 ° N), it disappears completely during the summer months. The distribution of water bodies in the region has been summarized by Barton et al [28]. From a biogeographic point of view, the area can be divided into two main areas: to the north, the southeastern limit of the North Atlantic subtropical gyre (NACW) and to the south, the north of the northeast tropical Atlantic gyre (SACW). The area includes part of the eastern edge of the subtropical gyre with the Azores Current (AC, for Azores Current) whose southern branch feeds the Canary Current (CC, for Canary Current), which flows along the African coasts. Arrived at the Cap Blanc level (21°N), the CC branches off to the east to form the Courant Nord Equatorial (NEC, for North Equatorial Current). South of Cap Blanc, we find the North Equatorial Counter Current (NECC) [29,30]. The two current systems in the region carry the water of very different temperatures. A frontal zone at their meeting point separates them with a strong thermal gradient [31]. This front is located at Cap Blanc in the hot season and at Cap Roxo in the cold season.

The coastline of the northwest African system is characterized by a succession of capes (Cape Ghir (31 ° N),

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Cape Yubi (28 ° N), Cape Bojador (26 ° N), Cap Blanc (21 ° N) and Cape Verde (15 ° N) and bays. The continental shelf is generally wide (50 km) compared to other large upwelling systems, reaching 150 km in the central part, around 25 ° N offshore Western Sahara [32]. Two groups of islands are found off the coast, the Canary Islands at 27 ° - 29 ° N and the Cape Verde islands at 14 ° - 18 ° N. The coasts senegalo-mauritaniennes are appreciably oriented in the meridian direction; the transport of Ekman to the broad one is produced there by the trade winds of north, northeast and northwest having a component parallel to the coast. These winds prevail in the region in winter and spring and are responsible for a vertical supply of nutrient-rich waters by virtue of the principle of mass conservation [33]. The movement of the Intertropical Convergence Zone (ITCZ) causes a clear alternation between a dry season which generally extends from November to May and a wet season from June to October. During the dry season, corresponding to winter in the northern hemisphere, the ITCZ reaches its southernmost position, while it oscillates north during the wet season - boreal summer. This area is characterized by high spatial and seasonal variability in sea surface temperatures (SST) and primary productivity. The southern part of the area is characterized by warmer and richer Chlorophyll-a waters than the northern part. Seasonal variations are also very marked. The temperature can vary from 16-18 °C in February-March (cold season) to 30 °C in July-October (hot season). Strong latitudinal temperature gradients exist in the region with a larger and narrower temperature change between 20 ° -22 ° N. These latitudinal variations in temperature depending on heat exchanges with the atmosphere and the intensity of the upwelling. The NW African ecosystem's nutrients distribution is typical of a coastal upwelling zone where cold waters rich in nutritive salts are advected in the euphotic layer where primary production develops. The fertilization mechanisms of the marine environment change according to the season and the region depending on the situation of the climatic action centers and the morphology of the underwater coast [34]. The two main bodies of water (NACW and SACW) have different nutrient contents. A significant southern-north gradient is observed with waters clearly richer in nutrients in the south [35]. In the North West African upwelling system, it is recognized that there are two types or phases of organic production: a so-called "balanced" phase where the phytoplankton and zooplankton peaks are simultaneous, and another so-called "unbalanced" phase where these two peaks are offset in time (the zoo succeeds - to the phyto) [34] and this has significant impacts on the productivity of the region. South of Cap Blanc, seasonal maximums of phytoplankton and zooplankton are in phase [36,37]. Further north and especially in Morocco, there is a significant gap between the development of phytoplankton which takes place in summer during the upwelling and that of zooplankton which is maximum in autumn or winter [38]. The NW African upwelling system is the most productive in terms of primary production of the four EBUS (> 5 gC m^2 d^{-1} and> 10 mg m^{-3} of Chl-a) [29,39]. This high productivity supports a wide variety of pelagic fish species.

5. Operating Modes

Fishing fleet

The exploitation of small pelagic resources in the Moroccan EEZ is carried out by three main types of means of production, which operate under different regimes legal access to the resource (fishing license and fishing agreement). These fleets differ according to their size and their fishing strategies.

The coastal fleet operates along the Atlantic and Mediterranean coast and is made up of: • Moroccan coastal purse seiners with a gross tonnage ranging from 50 tons (tx) to 130 tons and a variant power between 300 hp and 550 hp. The gear used is the purse seine, the characteristics of which vary according to the size of the fishing units, the fishing area and the size of the catch. The length varies between 350 and 460 fathoms and the fall between 40 and 60 fathoms. The bulk storage system in the holds, traditionally used in the Atlantic, has been gradually replaced by the use of plastic boxes for handling small pelagicin order to control the quantities caught and promote their quality. This system is almost generalized in the main ports (a limited percentage of bulk is still admitted, ie 30% at the level of the southern ports). • Spanish coastal purse seiners classified in the "artisanal pelagic fishing" section at the level of the 2014-2018 protocol of the Morocco-European Union fishing agreement. These vessels are authorized to fish beyond 2 nautical miles calculated from the baseline. Their fishing area is limited to the south by the parallel 34 ° 18'N. Fishing units with the possibility of fishing are of a tonnage less than 100 tx and use the purse seine as fishing gear. This fleet, which used to target anchovy (Engraulisencrasicolus) in the past, has now directed its effort towards fishing for sardines (Sardina pilchardus). An extension of the fishing zone to the south, up to parallel 33 ° 25'00''N is planned for 5 purse seiners. This measure is subject to regular evaluation in order to examine the possible interactions between the European Union fleet and the Moroccan fleets. 3.1.2 The offshore

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fleet This fleet operates south of Cap Boujdor and is made up of: • Pelagic trawlers Type RSW, flying the Moroccan flag, equipped with a conservation system on board type RSW (Refregerated Sea Water). The average Gross Tonnage (GRT) is 762 tons and the average engine power is 2524 hp. These trawlers are authorized to fish between Cap Boujdor and Cap Blanc (26 ° 07'N- 20 ° 46'N), beyond 8 nautical miles calculated from the baseline. The fishing gear used is the pelagic or semi-pelagic trawl, the size of the smallest mesh of which must be equal to or greater than 40 mm of stretched mesh. These trawlers operate under an individual quota system per boat. • Russian freezer pelagic trawlers with an on-board freezing system and devices for processing and processing fish into flour. They operate under the Morocco Russia fishing agreement. Russian trawlers have an average capacity of 6,334 tons and an average engine power of 6,515 hp. Resources and Fisheries for Small Pelagictock and Moroccan Fisheries Report 2016 30 • European pelagic trawlers: classified under the heading "industrial pelagic fishing" at the level of the 2014-2018 protocol of the Morocco-EU fisheries agreement. The gear used is the pelagic trawl, the mesh of the pocket of which is fixed at 40 mm targeting small pelagic, sardines and sardinella, as well as horse mackerel and mackerel. The units authorized to fish are of three categories: vessels of a tonnage greater than or equal to 3000 Gross tonnage (GT), vessels of a tonnage less than or equal to 3000 GT greater than or equal to 150 GT and vessels of '' a gauge of less than 150 GT. The accessible fishing area is located south of parallel 29 ° N These freezer trawlers should operate beyond 15 nautical miles calculated from the baseline. Concerning fresh fishing trawlers, they can exercise their activity up to 8 nautical miles from the baseline. These pelagic trawlers have an average capacity of 6,560 GT and an average driving power of 5,220 KW.

The artisanal fleet This fleet operates between Saidia and Boujdor. It is made up of small boats whose gross tonnage generally exceeds 2 tx for the majority while it can reach 8 tx in certain regions. This artisanal fleet is targeting small pelagic has constantly been developing in recent years. In fact, by the end of 2014, approximately 2,000 boats employing more than 10,340 fishermen had practiced the fishing activity for small pelagiceasonally or permanently. The majority were identified in the central area between Safi and Boujdor. In the Mediterranean zone, two regions are distinct according to the type of fishing unit used and the fishing methods for small pelagic:

- Eastern Mediterranean: the small seine is used by boats operating at night and essentially targeting the sardines and horse mackerel. The fishing operation is done by means of two units: (1) the active boat (Mampara) having the design of a large boat (5 to 7m) decked with inboard engines from 60 to 120 CV, (2) the boat au feu (lamparo) is used to attract pelagic fish by the light of lamps. Fish gather near the boat before surrounding them with the purse seine. There are two types of lamparo, electric and gas.
- Western Mediterranean: the small seine is used by fishing units locally called "Chebbaks". The fishing unit is composed of three boats: (1) the boat whose length can reach up to 9 m and a maximum tonnage of 5 GRT, (2) the fireboat (lamparo) and (3) a small rowboat to hold the front of the seine. • Atlantic: in the Atlantic zone, the small seine is used by boats, particularly at the level of the ports because of the existence of a port infrastructure favoring safe exits and returns, but also with the availability and the ease of fuel and ice supply. Fishing is practiced by a single boat in the entire region north of Safi and by two to three boats in the Resources and Fisheries of Small Pelagictate of stocks and Moroccan Fisheries 2016, 31 regions south of Safi. The period of use of the small seine varies from one port to another. It is dependent on the climatic conditions and the availability of the caught product. The small seine called "Swilka" has a length that varies from 60 to 350 fathoms and a width of 8 to 50 fathoms. The stretched mesh of the net is 9 mm. Fishing activities generally take place near the coast at depths between 10 and 50 fathoms.

6. Conclusions

The sardine stocks located along the Moroccan Atlantic coast live and breed in seasonal or permanent upwelling areas. Upwelling is by its very nature a dispersive, fluctuating process that varies widely from year to year, from area to season and from season to season. For sardines, it seems difficult to satisfy the retention constraint, which is an important process conditioning the existence and long-term maintenance of a population in a given environment [40]. Sardines are, however, capable of developing huge biomass. This is the result of an adaptation of the reproductive strategies to the environmental characteristics of the upwellings in order to offer optimal conditions for the development of the larvae. In the central zone (28-32 ° N) of the Atlantic coast of Morocco, the main spawning season is offset from the upwelling season.

In short, a responsible attitude towards this resource requires the conservation not only of specific diversity but also that of the entire genetic heritage. Therefore, responsible management must have as a preliminary stage the definition of management units that necessarily involve identifying population units constituting a stand, particularly when it comes to small pelagic known for their instability as well in time than in space. Therefore, the need to improve scientific knowledge on the biology of the species (area and spawning period, diet, stock unit, etc.), on migration, and the conditions of its exploitation s' is gradually imposed.

The importance of respecting the biological rest period of the agarophyte G. sesquipedale which provides economic benefits for rural communities along the coasts where the algae form important deposits; - Adopting responsible behavior in harvesting and encouraging the uprooting of gelidium thalli whose size is greater than 10 cm. Indeed, a thallus that does double weighs twice as much and contains more agar; - Respect for the ecosystem including not only marine plants but also other forms of marine life; - Raising the awareness of divers as to the danger which threatens the resource if the rocky substrate is destroyed or degraded, it represents the support and the point of fixation of the algae.

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