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FLOOD PULSE IN A SUBTROPICAL FLOODPLAIN FISHERY AND THE CONSEQUENCES FOR STEADY STATE MANAGEMENT

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ABSTRACT
This paper integrates biological and social dimensions of the Okavango delta fishery by reviewing all available literature. The main aim of this review is to support development of policy for comprehensive management of the delta's fishery on the basis of the existing water management regime. Based on the review, it is evident that the flood pulse contributes towards fish production and productivity in the delta. Some research in the delta shows that, typical with other floodplain systems globally; the terrestrial ecosystem is actively subsidizing the aquatic system whereby this energy is eventually channelled into fish biomass. This fish biomass is then exploited by different fisher groups in the delta using a variety of fishing gears. Subsequently, similar to other floodplain fisheries elsewhere, fish is a major livelihood activity in the delta. Management of fisheries resources globally has been based on classical fisheries management approaches. However, the efficacy of these is questionable due to collapses of some world fish stocks. This paper advocates a paradigm shift in fisheries management. A new management paradigm that is holistic in nature, with heavier emphasis on empiricism and less reliance on statistical or mathematical modelling needs to be formulated.

KEY WORDS
Flood pulse; fisheries management; paradigm shift

1. Introduction

Global forecasts show that fish constitutes the fastest growing food source in the developing world. Consequently, fish is expected to become a major source of 'food security, nutrition, diet and income of poor people in the developing world during the next two decades [1]. Floodplain fisheries are slowly becoming important focal points for fish production because they are usually accessible to populations living nearby. They are not only characterized by diverse species assemblages [2..3], but also have different use values that ultimately pose serious management challenges [4]. Many studies have focused on either the biological dimension (e.g. [5..9], etc) or socio-economic aspects (e.g. [10..14] etc) of floodplain fisheries as separate entities. This has resulted in a fragmented management approach, mostly using classical fisheries management approaches (or derivatives thereof). However, a comprehensive management of fisheries resources in these valuable ecosystems can only be possible if the two major issues (i.e. biological and social dimensions) are fused into an integrated approach. Moreover, the impact of the flood pulse on fish production, and the prevailing exploitation regimes in such systems, need to be acknowledged in the management paradigm.

The main aim of this review therefore, is to synergise and synthesise the biological and socio-economic information that exists on the Delta's fishery, and present an alternative approach that can be useful for policy formulation. Therefore, the objectives of this paper are (a) to highlight the intrinsic importance of seasonal flooding in the Delta, towards both (i) fish production and (ii) utilization; (b) to then discuss the management challenges that exist in the Delta's fishery and (c) to finally propose management approaches to ensure sustainable utilization of the Delta's fish resource.

2. Habitat Diversity, Flood Pulse and Fish Prodcution

The Okavango Delta is categorized into three broad ecotypes, the upper portion which comprises of the permanent water bodies of the Delta, and the lower Delta, which is characterized by seasonal floodplains and the higher dry land masses [15]. Meanwhile, there are about six major habitats in the Delta: Perennial swamp; perennial and seasonal swamp; floodplains; rivers, *melapo* and water courses; *madiba*; islands and mainland edges [16]. Each one of these has a diversity of micro-habitats utilized by different fish species. Seasonal flooding in floodplain systems "influences the shape, size and complexity of river channels, the distribution of riffle and pool habitats, the structure of aquatic habitat, the amount and type of food available, and the nature of the interactions between the main channel and the floodplain" [17].

There are 71 fish species in the Delta [18.19] distributed heterogeneously throughout the different habitats. The multi-species complex characterizing the Delta's fishery agrees with other research that assemblages in inland waters are relatively complex [2]. There are possibly two major fish stocks in the Delta; the upper and lower Delta stocks characterized by different population dynamics (e.g. growth, mortality, etc) [20]. Moreover, fish species distribution in the Delta has spatial variations where some species such as *Hydrocynus vittatus* (tiger fish) occur mainly in the upper Delta and are only found in the lower Delta during years of exceptionally high floods [20..22].

Habitat preference is one of the major factors determining species distribution and abundance in the Delta [22]. Furthermore, the permanence and flow rate of water are some of the most important factors influencing the distribution of fish in the Delta [19]. Strongly rheophilic species such as *H. vittatus* and *Nannocharax macropterus* are restricted to 'riverine floodplain and perennial swamp' while species like *Hepsetus odoe* prefer well-vegetated areas [22]. The high oxygen demand under papyrus mats suggests that these kinds of habitat support low fish abundance, and would generally be inhabited mostly by species with a high tolerance for low oxygen (e.g. Clarias spp, Ctenopoma spp, etc)[23]. Furthermore, the tangled mats of grass on the Delta's floodplains provide suitable fish spawning habitat [24].

2.1 The Flood Pulse Concept (FPC)

The flood pulse concept (FPC) is founded on the observation that some river systems fluctuate between 'terrestrial and aquatic' phases seasonally as a consequence of the flood regime [25]. The flood pulse is the major driving force that promotes connectivity between major seasonal floodplain habitats [13], which suggests that the seasonal floodplain can disappear without the flood pulse [19]. It has also been described as the main trigger of seasonal ecological transformation in major tropical rivers like the Amazon, the Mekong and the Congo [26]. Essentially, the flood pulse in floodplain systems promotes rapid recycling of nutrients and organic matter [6], and also plays a crucial role in the decomposition of organic matter through bacterial action [27], which occurs seasonally in the seasonal floodplains [24].

Similarly, the Okavango Delta is characterized by a flood pulse [28], that drives dissolved organic matter (DOM) down the Delta [29] derived mainly from plant material as a consequence of the seasonal flooding [30]. This reflects previous findings which observed that terrestrial detritus gets captured into the aquatic biota by seasonal flooding in the Delta [24]. Therefore the annual flood is an important conduit of organic matter transport in the Delta [31].

Floodplain fish species undertake seasonal migrations for feeding and spawning as a consequence of seasonal flooding [32]. These migrations are characterized by lateral and longitudinal migrations in the Delta [22]. This agrees with other research elsewhere [6] which described similar migratory patterns within the Central Delta of the Niger River (Mali), where most species migrate for spawning. Similarly, some fish species of the Parana River in the Amazon have adapted their spawning to the flood pulse [3].

Moreover, some fish species such as the catfishes (Clarias spp.), undergo seasonal feeding frenzies (termed the catfish run [33]) where they feed voraciously on their preferred species, *Marcusenius macrolepidotus* [22]. Furthermore, *Schilbe intermedius* (the silver catfish), a highly opportunistic predator, takes advantage of seasonal food availability in the Delta as a consequence of seasonal flooding to enhance its survivability [20]. It actively feeds on terrestrial insects that drown in the rapidly advancing flood [20..21], and also feeds on mice drowned by advancing floods [20]. Therefore, the flood pulse, apart from releasing nutrients into the aquatic system from the terrestrial environment, also makes food available to fish stocks which are then turned into biomass necessary for production.

2.2 Fish Production and Productivity

The FPC predicts that most primary and secondary production of wetland systems occurs in the seasonal floodplains [3]. In essence then, the flood pulse enhances biological productivity in floodplain systems [34]). In some shallow floodplain lagoons of the Delta, this process is observed through localised 'boom and bust' conditions [23] similar to what has been described in Australian river systems [35]. Furthermore, the abundant large mammals in the seasonal floodplains introduce substantial phosphorus loading into the aquatic system at the end of the flooding period, which then enhances primary production [36]. These processes promote zooplankton production which is excellent food for juvenile and sub-adult fish [24]. Moreover, low-flood years restrict fish migrations into the seasonal floodplains which restrict fish production in the floodplains. Conversely, high flood years result in increased fish migrations into the seasonal floodplains, which results in massive spawning and a channelling of zooplankton into fish fry [36].

This observation, where the terrestrial environment is actively subsidizing the aquatic system, agrees with other research [3] which highlight that the FPC predicts the exchange of nutrients and energy between the aquatic and terrestrial systems. It is perhaps on the strength of this observation that a strong relationship between floodplain fish growth and floods exists [8]. Years of high floods were correlated to high growth rates of *Colisa fasciatus* and *Channa punctata*, with significantly higher yields of these species. Fish growth in high flood years is so high that two cohorts comprise catch; young-of-the-year fish in their first year of life and survivors from the previous year [8]. It is possible that this relationship exists in the Delta for some fish species.

Vegetation and detritus are the major sources of energy conversion into fish biomass in the Delta, while insects constitute a small proportion of diet [23]. This is based on the observation that the majority of the Delta's fish species (e.g. breams/ tilapia) feed mainly on algae, periphyton and vascular plants. However, it was observed that this food link changes in shallow seasonal floodplain lagoons where zooplankton is the predominant diet [23]. Moreover, the flood pulse provides optimum hatching conditions for diapause zooplankton eggs resting in floodplain sediments [24] which support increased primary production. It is equally possible that diapause aquatic invertebrates' eggs are also hatched which also contributes food for fish juveniles and sub-adults. Ultimately, these energy sources are also channelled into fish production in the seasonal floodplain.

Hydrological connectivity provided by seasonal flooding is the major factor in promoting fishery production and yield of *Prochilodus lineatus* in the Parana River (Brazil) [5]. In this system, seasonal flooding provides accessibility to floodplain lagoons by *P. lineatus* where it lives on 'fruits, leaves and floodplain grass' until it reaches maturity before back-migrating to the main riverine habitat. Similarly, it was also observed that several catfish species fed on red mulberry and swamp privet fruit in the Mississippi River (USA) floodplain [7]. Moreover, *Cichla temensis* species in the Cinaruco River, (Venezuela) floodplain preyed heavily on *Semaprochilodus kneri* which were back-migrating from the seasonal floodplains [9]. Floodplain fish feed actively on fruits, flowers and terrestrial insects from the inundated floodplains, and are in turn preyed upon by herons and vultures when they get trapped in drying floodplain pools [13]. Moreover, the flood ensures improved breeding, growth and survival as flood levels and duration increase [2]. In conclusion, these observations agree with others [37] that the productivity of tropical floodplain fisheries is correlated to the seasonal flood regime, where fish production (and yield ultimately) depends on both the extent of flooding during high water and the amount of water retention in the system at low flood levels [38]. These observations suggest that the flood pulse contributes significantly to fish production and productivity in the Delta, which then supports a dynamic multi-gear fishery that is a major source of rural livelihoods.

3. Structure of the Fishery, Utilization and Management

Traditionally, the main fishing groups in the Delta were the Hambukushu, the Bayei and the Basarwa [39..40] and still remain to the present [41..44] involved in subsistence and commercial fishing [41..42]. These fisher groups use different fishing gear harvesting different fish species [45]. Female subsistence fishers predominantly use fishing baskets [39, 42], while male subsistence fishers predominantly use homemade gill nets, traditional hook and line, and fishing spears while commercial fishers use multi-filament gill nets [42]. There are also recreational fishers (local and international tourists) using modern hook and line fishing equipment [42]. Generally, subsistence fishers in the Delta are extremely impoverished [46] with limited productive and financial assets [47]. Despite the utilization of modern fishing gear in the fishery, it has been described as a predominantly artisanal fishery due to the crude and inefficient fishing gear used [48..49]. Despite this characterization, this fishery is the mainstay of rural livelihoods, both as a source of cheap, yet high value protein [47] and is also a major source of income for the small-scale commercial fishery that exists [44, 49].

A tremendous amount of indigenous traditional knowledge is employed by some fishers to harvest their preferred fish species [50]. Skill is also employed in the construction of some of the fishing gears used in the Delta. Invariably, the Delta's fishery is a fountain of traditional norms and systems whereby fishing is not only a source of livelihoods, but also a socio-cultural expression.

Various government initiatives effectively developed the Delta's fishery, from subsistence fishing in the 1960s [51] to a small-scale commercial fishery using modern fishing equipment in the 1990s [48] until the current period where government has provided grants to improve fish marketing [49]. This commercialization was effective because commercial fishing became the second most important economic activity in the region in the 1990s [49] and remains one of the key livelihood activities [43..44]. Moreover, commercial fishing in the Delta is an economically viable enterprise that offers positive investment opportunities [52].

These observations agree with [14] who observed that wetland fisheries are a major source of economic activities for people who live within their periphery. Similarly, the floodplain fishery of the Sao Francisco River (Brazil) is an important economic activity for its local fishery [12]. Furthermore, the commercial fishery of the lower Amazon is not only a major source of cheap, yet high quality protein; it is also the major contributor of regional employment and income [11]. Moreover, lower Amazon fishery is an important source of livelihood for the local communities who live in the area [10].

3.1 Sustainable Utilization and Holistic Management, Concerns, Debates

Perhaps as a consequence of different exploitation regimes, and competition for a similar resource by some of the fisher groups, the Delta's fishery is characterized by conflict [41..42], that is normal in fisheries with competing uses [4]. Most of this conflict was predicated on allegations of commercial fish over-exploitation [41], even though it was more about access than about over-exploitation [42]. Furthermore, the lack of clearly defined user rights may have also contributed to these conflicts in the fishery [53].

Concerns about over-exploitation were unfounded because the Delta's fish stocks are currently not biologically over-exploited [41], and the multi-gear fishery is exploiting the multi-species fishery rationally [45], which is the best exploitation regime for this kind of fishery [54]. This also agrees with other observations that the Delta's fish resources are not degraded under the present fish exploitation regime [53].

The lack of a national fisheries policy, which has been debated since the 1970s [55] continues to be the major impediment to fisheries development in the Delta. This policy should clearly state the management objectives which are the main cause of fisheries management failure [56]. These management objectives should be consistent with the objectives of the national fisheries policy [4, 56]. To sum up the challenges facing fisheries management in the Okavango Delta; "the Okavango Delta fishery is not a homogenous entity but is characterized by spatial variations in the nature of the fish stocks/communities and the exploitation regime. There is higher species diversity and fishing effort in the upper Delta, while the opposite prevails in the lower Delta. The lack of a national fisheries policy, the development of a well intentioned but unfocused Panhandle management plan, and the weak legal framework of the wildlife management areas (WMAs) and controlled hunting areas (CHAs) have contributed to an incoherent management of the Delta's fish resource"[57]. Over and above these, some of the key issues facing fisheries management in the Delta include use of multiple gears, multiple use values, open access and conflict.

Several classical management approaches for inland fisheries include technical measures (i.e. mesh regulations, gear limitations, closed seasons and closed areas), input controls (i.e. licensing, state-regulated access, ownership), and output controls (quotas, size limits on fish landed) [58]. It was on this background that some management approaches proposed for the Delta include: licensing, effort limitation, closed seasons, mesh size regulation, limitation on night-time fishing activities, segregation of fishing areas [18]. Moreover, classical fisheries management approaches have been proposed within the recent Okavango Delta Management Plan [59], which include input controls, output controls and technical controls. The biggest question now facing fisheries management in the Delta is whether these management approaches are feasible, or are indeed redundant.

3.2 Need for a Paradigm Shift in Fisheries Management

The basic objective of fisheries management is to determine effort levels in the fishery which give the maximum sustainable levels (MSY) [60]. This suggests that it is important to limit the minimum size of fish under exploitation in a fishery in order to achieve maximum sustainable yields (MSY) [61]. Subsequently this yield is reached at a minimum length at which a fish year-class has reached it maximum growth in weight, at a point in its growth where growth rates are equal to mortality rates [61]. Subsequently, the relationship between fish stock and yield, based on selective fishing through mesh regulations, was codified into the ''yield-per-recruit-model'' [62], and subsequently 'tropicalized' [63]. As a modification of this MSY concept, fisheries also began to be regulated on the basis of achieving economic efficiency [64]. Moreover, classical fisheries management is predicated on stock-recruitment models based on equilibrium assumptions [65], even though there is no credible evidence linking stock size to recruitment [66]. These assumptions have subsequently become the "Achilles heel" in the classical fisheries management paradigm.

Contemporary fisheries management "ignore(s) the Darwinian consequences of selective harvest" [67]. This is based on the observation that selective harvesting, based on mesh size regulations, favours slow growing individuals maturing earlier or any attribute that favours "lower population productivity" [67]. Fishing causes selective evolutionary changes in exploited fish stocks related to sustainable yield [68]. The phenotypes that are normally affected by selective fishing are "growth rate, length- and age-at-sexual maturation, and fecundity" [68]. Therefore, strong selective fishing pressure on fish populations causes maladaptive changes by effectively warping the fishes' adaptive landscape. This is then expressed through a failure by exploited fish stocks to regain their productive capacity [69]. In essence, selective fishing through mesh regulations affects fish populations at both the ecosystem level and the individual species level [70]. At the ecosystem level, selective fishing removes apex predators [71] where bottom-up processes might begin to predominate in system that evolved initially as top-down controlled [72].

There is need for a paradigm shift in fisheries management on the background of repeated failure of classical fisheries management approaches to save most major world fisheries [73]. Most major world fish stocks have either collapsed or are declining [74..77], which is indicative of not only stock failure, but also policy inadequacy [65]. Moreover, some of these collapses were possibly due to 'uncertainty' in fish stock estimates which resulted in unreliable estimates of optimum fishing levels [76]. Fisheries can only be sustainable when uncertainties that are prevalent in fisheries modelling are incorporated into planning [56].

This reinforces the call for a paradigm shift in fisheries management, especially for floodplain systems such as the Okavango Delta. The classical fisheries management techniques currently used were developed for single species fisheries in temperate systems, and were subsequently transplanted into multi-species, multi-gear tropical fisheries. Undoubtedly, technical controls such as mesh regulations are harmful for the fishery. Gear limitations in a multi-gear fishery, would disenfranchise the majority of artisanal fishers to whom fish is a major source of livelihood. Moreover, this will also affect the culture of fishing communities to whom fishing is also a form of cultural expression. Closed seasons, unless they are tied to the prevailing exploitation regime in the Delta where fishers periodically leave fishing for farming pursuits might be meaningless. Some research has showed that closed fishing areas in the Delta are ineffective [57]. Output controls are invariably based on the MSY concept which has been the bane of most major world fisheries as discussed already. Input controls, which focus on ownership and user rights, can cause more conflict and tension within fishing communities, especially in the Delta where conflict is still a prevailing management concern.

One undeniable observation is that fish behave more like insects than other vertebrate animals. Fish undergo boom and bust conditions depending on prevailing environmental conditions and a host of other factors. Therefore, any proposed management approach should take this 'chaotic' nature into consideration. More emphasis should be placed on empiricism than modelling, because models are invariably based on faulty data and unrealistic assumptions. These faulty data and unrealistic assumptions invariably introduce uncertainties in fisheries models that lead to uncertainties in management [56]. Moreover, models assume a more linear and mathematical orientation of the nature of fish populations which is at variance with their chaotic behaviour in nature. This discussion highlights the argument that "conservation biology and fisheries science are both disciplines that have focused on single species or single populations, and that have developed strong quantitative and theoretical bases"[78].

4. Conclusion

The literature suggests that there is need for a paradigm shift in fisheries management, especially in floodplain fisheries. The new manegement regime should focus more on empiricism instead of statistical or mathematical models. The reality is that the Delta's fishery is extremely dynamic, and complex. Furthermore, the Delta is a major source of not only livelihood for the local communities who live within its periphery, but it is also a cultural artifact that needs to be acknowledged in a new management approach. However, a new management regime needs to be informed by a fisheries policy still to be developed. It is imperative that this policy be developed using the opportunity that a better understanding of the weaknesses inherent in classical fisheries management theory offers.

Moreover, the literature has also shown that the flood pulse is the main driver of ecological change in the Delta's fish community. The presence of a seasonal flood pulse ensures high fish production that is a major source of rural livelihoods. Subsequently, any developments that may affect the pulsing nature of the flood regime may negatively affect the livelihoods of these rural communities. Hence, an integrated water management system of the Delta needs to acknowledge and safeguard this intrinsic attribute of the Delta that is the source of such high biological production.

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