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Spatial Structure effects on Fisheries Management for Lake Victoria's Nile Perch

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Spatial Structure effects on Fisheries Management for Lake Victoria's Nile Perch.*

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Abstract

Lake Victoria, globally the second-largest freshwater Lake by surface area, houses an artisanal Nile Perch Fishery that directly involves around 200K people. While the whole Lake surface is potentially available to fishing activities, the fishing vessels' operational and technical characteristics, in conjunction with fuel costs, create stark differences in the access costs between areas close to the shore and those farther away (up to 70Km from the nearest dry land). Evidence indicates that most fishing effort is made very close to the shore. There is an imbalance between the fish stock distribution and the fishing fleet's ability to access and profit from it. Nonetheless, this aspect has not been considered in the literature, not in its consequences nor in the way it can be leveraged for management purposes. This paper employs a model replicating Nile Perch Fishery's most critical spatial aspects. It explores the potential of a Policy declaring the central areas of the Lake as Reserve areas. While not a first-best Policy, it reduces the costs in patrolling activities, benefiting and levering the higher costs of reaching reserved areas. It reduces the variance in the system as it is perturbed by external factors, e.g., prices, and hence, it increases its resilience to external shocks.

JEL Classification: O13, Q22, Q28

Keywords: spatial effort distribution; natural resource management; management strategies; reserve areas; fisheries.

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1 Introduction

Lake Victoria has a surface area of 68,800 km2, giving its shape, opposite sides can be up to 250 km apart. It houses a very dynamic open fishery, that have as main species Nile Perch -NP- (*Lates niloticus*), destined to international markets. Despite evidence that the fishing effort is concentrated in areas close to the shore (Peter and van Zwieten, 2018), there has been remarkable few attention given to the role that this aspect has in the Fishery.

The potential presence of low levels of effort in some areas of the lake that are not close to dry land (Island included), combined with the evidence of at least as high stock densities in those same areas (LVFO, 2019) as the stock densities present in closer to the shore fishing grounds, opens the possibility of the existence of a, *de-facto*, reserve area that helps the system keep its stability.

The Nile Perch Fishery operates as an open access fishery. While it is considered to be in a state of over-exploitation, the fishery has maintained a consistent overall productivity over the last decade (Kolding et al., 2014). A high level of exploitation that has been stable in the last years can be regarded as not the worst case scenario considering the difficulties in the fishery management. Nonetheless, this over-exploitation can make the overall system too susceptible to external factors that can potentially drive it out of the current equilibrium to a situation of far less output. There is no consensus about the reasons of this relative stability.

Currently, fisheries management in Lake Victoria is being implemented mainly through controls of the type of gear that is allowed to be used in fishing activities. This is done through a combination of visits by enforcement units at the Landing Sites and through patrolling of the Lake. As the enforcement is based on the gears used, either size of the hooks or the mesh size of the gillnets, these activities require additional effort as this characteristics must be checked with a close inspection to the gear.

Traditional management methods that are applied in other contexts to manage the Fishery are not possible to apply in Lake Victoria. The enforcement capacity of the local governments are not enough to implement quotas or restrict the number of boats allowed to fish in the Lake. So far, strict enforcement of gear regulations has not been very successful either (Obiero et al., 2015; Cepić and Nunan, 2017). We suggest that a policy that takes advantage of the already existent hurdle to reach far-from-the-shore areas can be an alternative management strategy worth considering.

This paper starts presents the evidence on distance effects on Lake Victoria's Nile Perch Fishery. This starts by presenting the data relative to the extent of the Lake, and then using the available data to show the distances that are most likely covered by fishers. As going into far-from-the-shore areas does not make economic sense, unless there is fish to be catch, I present current evidence on the distribution of the stock in the Lake that state that there is fish to be catch in the middle of the Lake. Then, a simple model that reproduces this spatial dimension of the fishery is presented. Using this model, two different scenarios are simulated in which the system is exposed to changing values in the price of fish and fuel, the two main prices that drive the decision of the fishers, and that because they are set in international markets, they are not controllable in the local context. In one of the scenarios there are no restrictions in fishing; and in the other one, a restriction is present that ban fishing in the center of the Lake. The consequences of such policy over the dynamics of the system is analyzed.

2 The Spatial Dimensions of the Fishery

The general principle upon which this paper relies is the accessibility of a lake surface for fishing activities. As all activities are to be started and finish in dry land, how far a fishing ground is located has a strong weight on the profitability of fishing. Distance translates in costs, which is particularly expensive if those distances are covered with overboard motors as is the case in Lake Victoria. The next figure (1) presents a simple example of the differences that shapes produces in accessibility. In a round shape areas are up to three more times farther away from the border.

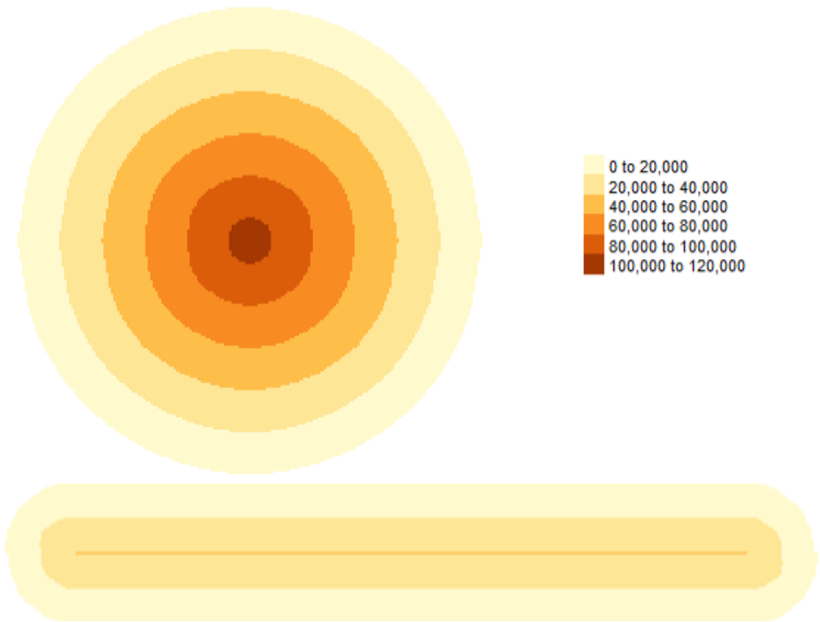

Figure 1: The same area in two different shapes. The distances to the border are quite different depending on the shape. Lake Victoria it is not only quite large, but also nearly circular in shape.

Although in most situations this is not very relevant as most lakes are not of such large extensions. Lake Victoria is extremely large and, differently to other big lakes in Africa, almost round. Distances here are necessarily an issue.

2.1 Fishing distances

The following figure (4) presents the distance to the closest dry land from each location on the surface of the Lake. It takes distances as a straight lines to the nearest point in dry land, either on the shore of the lake or in a island. There are many landing sites, of all sizes, scattered all around the borders of the Lake an the different Islands. This makes this map a good approximation to the actual conditions that fishermen face to reach the different fishing grounds over the Lake.

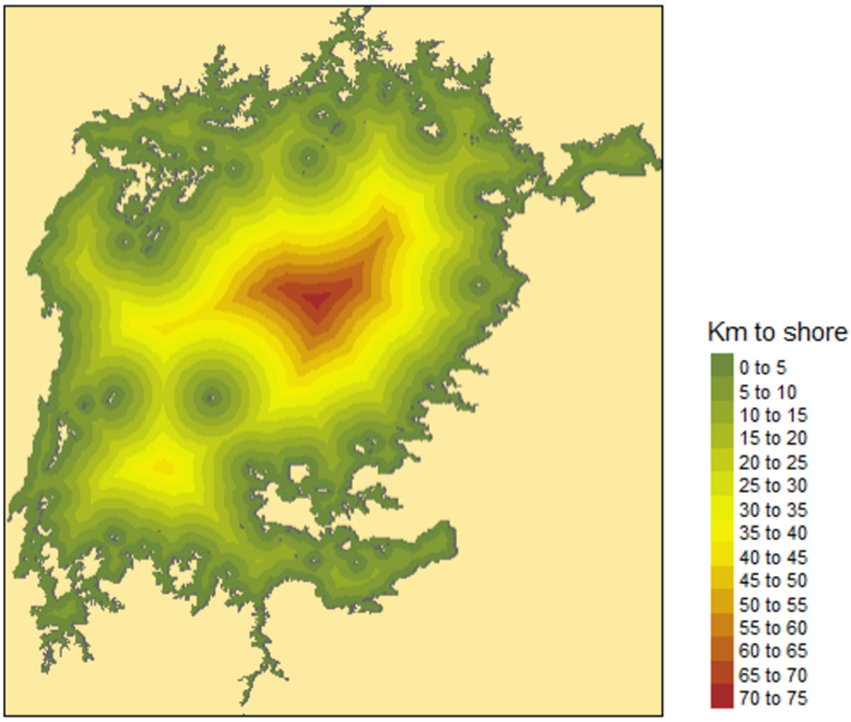

Figure 2: Distances to dry land in Lake Victoria.

Direct evidence concerning the distances that fishers travel to the fishing grounds comes from Peter and van Zwieten (2018). They trained a group of 19 fishers to use GPS devices to record their fishing excursions during several months (between 2010 and 2011). The results of the data collected is presented in the next graph. They found a distinction between gillnets and longlines boats; the latest traveling farther into the Lake. Nonetheless, the distances are clearly short compared with the potential places to be covered. For gillnets the average distance was 5 km, and for longlines was 7 km.

In 2021, I conducted a survey among fishers in different location along the shores of Lake Victoria in different regions of the three countries. Boat owners and crew members targeting Nile Perch were interviewed. A total of 324 valid responses were col-

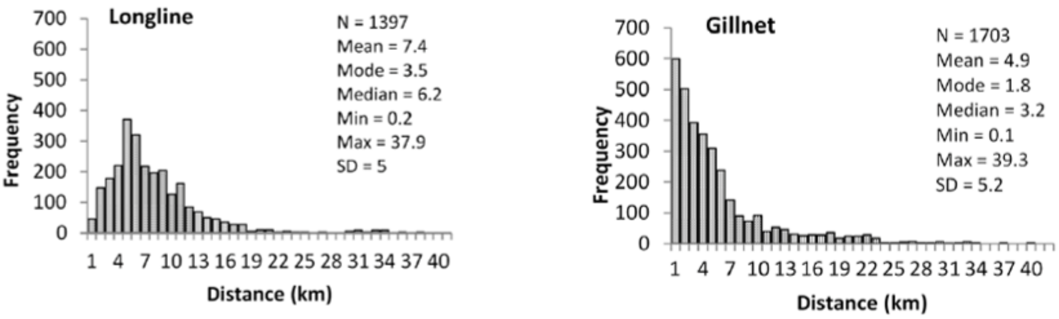

Figure 3: Distances travel in the Lake by fishers, 2010, taken from Peter and van Zwieten (2018).

lected. Among the questions, fishers were asked about the time expended to reach fishing grounds. Question regarding distances were not included, after a pilot showed unreliable responses [1].

The following graphs show the distribution of responses for Nile Perch fishers, and the distributions among the main two types of gear used in the Fishery: longlines and gillnets. Note the differences between the two types of fishers. With the median for gillnet fishers fishing being 1 hour and the median value for longline fishers 2 hours. Also note that there is a group of longline fishers that travel between 9 and 12 hours.

Although, there is no accurate available figures about distances, the general consensus among fishers and local officials is that this translates between 4 to 7 km in an hour. This also agrees with operational reports for this type of boats-engines pairs (FAO, 2012). Using this information, it appears evident that most of the boats cannot reach some areas of the Lake, as 6 hours of travel will only bring boats up to 30 km of the shore, at most. It seems that only the group that report over 6 hours of travel (with an average of 11 hours) is able to reach farthest-from-land locations in the Lake. Importantly, this corresponds with reports of several days fishing expeditions into the areas farther away from the shore (Medard, 2015). These travels are more expensive than the one-day

[1]Fishers struggled to get a figure for this kind of distance questions

trips, ice must be provided to preserve the fish and it uses necessarily more fuel. In the mentioned survey the presence of this long travelers accounted for a 4.5% of the total amount of surveyed Nile Perch fishers.

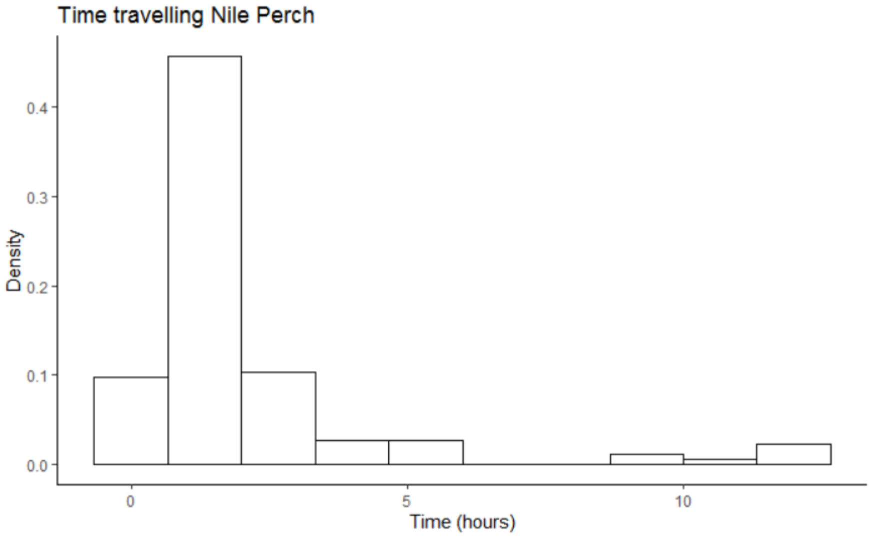

Figure 4: Distances travel in the Lake by fishers, 2021, Lake wide survey. (Peter and van Zwieten, 2018).

2.2 Stock Distributions

All the previous discussion only acquires relevance, if there is actually fish to be catch in the middle of the Lake. Evidence from the hydroacoustic survey implemented by LVFO provides support for this affirmation (LVFO, 2019). Using the data from the hydroacoustic survey a map of the distribution of the catch for the period of September-November 2020 is presented. It reflects biomass for Nile Perch above 50 cm of longitude, which it is the size at which it start to be legal to take a fish out of the water. See figure 4. Not shown here, an analysis of other years reveals that this pattern is not constant, and that the location and shape of the fish “blotch” is highly variable. It is common to get high density reading in this far-from-the-shore areas.

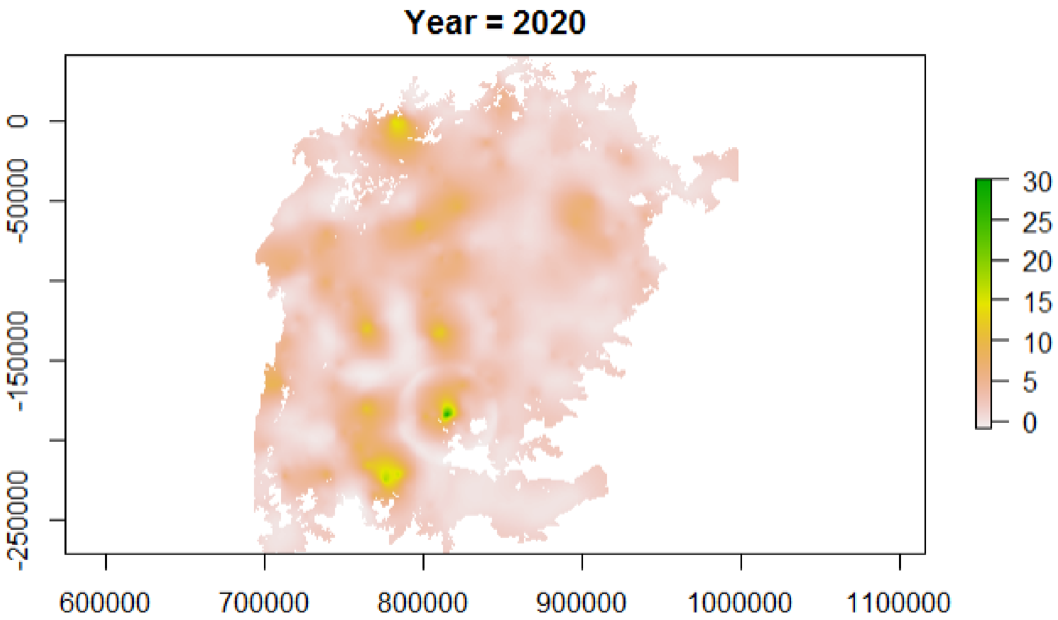

Figure 5: Distribution of over 50 cm Nile Perch Biomass over Lake Victoria. Tons / sqr. Km. Source: LVFO (2019).

3 Methods

To understand the consequences and management potential that this imbalance between fishing effort and fish distribution has on the Nile Perch Fishery a simplified model of the Fishery was implemented in R (R Core Team, 2021; Tennekes, 2018; Hijmans, 2021; Pebesma, 2018). It takes as given the spatial structure of Lake Victoria. Over this background, an open access fishery operates.

Fishers has access to three different types of technology. They diverge on the type of propulsion that is used. i) There are paddle boats; this has a very low entry price as there is no need to pay upfront to go fishing. Nonetheless, this boats cannot get very far as they spend too much time to reach fishing areas. ii) There are motor boats, this boats have a higher entry point as money for the fuel and the repairs has to be bought, this boats can reach farther into the lake. iii) Finally, there are motor boats that make multiple-day fishing trips. This are more efficient than motor ones to go father into the lake, as they make savings in the amount of fuel to be expended. Nonetheless, upfront cost are higher as ice, an sturdier boat and more knowledgeable crew must be hired (Medard, 2015).

At each point in time, the decision of each boat crew is to maximize profits, given a fishing ground. As all surface points are available and there is free entry, at the end, there will be fishing boats using the most profitable technology in each place. The key exogenous variables of the model are: i) the fuel costs, ii) the fish price, iii) the distance to each fishing location, iv) the fish stock distribution over the Lake.

The stock follows a Gordon-Schaeffer dynamics. The distribution is exogenous and stay constant (in relative terms). The stock total amount is not constant and it is determined endogenously. It depends on the level of overall extraction, the underlying factors that determine the maximum carrying capacity, and the growth of the stock between periods as a function of remaining stock (after extraction).

3.1 The model

The decision of each boat owner depend on selecting a technology, t, to fish in a particular suitable location, j. The technologies available are paddle: d, motor: m, and motor with multiple days trips l. Besides propulsion technologies that change the costs of travel, all the boats have the same fishing technology, defined by a common efficiency of the catch: e. The relevant factor is the profit: $y_{t,j}$, it depends on the fish selling price: p, The underlying stock density: S_j, the fixed costs of employing particular technology f_t, the fuel prices: g, and the distance to the nearest dry land: D_j.

$$y_{tj} = peS_j - D_j g - f_t \tag{1}$$

The selection of the technology is relatively simple. At each point there will be fishing activity, if at least one of the fishing technologies provide positive revenues. From those that provide positive revenues, the one that provides the highest revenue will be the one chosen. As all the agents are the same, the decision is the same for everyone.

$$t = argmax_t\{y_{t=p}, y_{t=m}, y_{t=mlt}\} \tag{2}$$

Note that the extraction of each boat is proportional (linearly) to the stock density at each location. Places with higher profit levels attract more boats. These have to share the resources in that location, and reduce the overall profit of each one. This is an open fishery, so fishing boats will continue to show up until the opportunity costs is reached (c), and no more fishing boats can get into the location without incurring in negative earnings.[2]

$$\hat{y}_{ijt} = (1 - \beta(n_j - 1))y_{ijt} = c \tag{3}$$

This is the same for all the locations with profitable fishing practices. A equilibrium will be reached in which all the boats have the same rent extraction, that for each boat will be the opportunity cost of going fishing.

An essential part of the model is the spatial layout of Lake Victoria, particularly the distances to the nearest shore over the surface of the it. We use the map of the Lake Victoria Shore (Hamilton, 2016), including all the islands, which are base camps for fishing activities, and divide the surface of the lake in square cells of 800 meters by the side. The distance to the nearest point over the border of the lake is calculated from the midpoint of each cell. This value is assigned to the overall cell. This create a fixed map with all the distances over the surface of the lake.

The next spatial dimension is the stock density over the surface. A nonlinear function relates the distance to the stock density. It is quite low in areas close to the shore, but very rapidly increases up to around five km, and then it continues to grow but a much

[2] Opportunity costs are the same for all boats. This can be made to vary across technologies, assuming, for example that opportunity costs are higher for owners that go with a more expensive boat.

lower rate. This aims to fit the empirical facts, that a lot of fishing activity is done around 5km away, and to the fact that there are higher densities in the middle of the Lake but these are not dramatically higher.

$$S_j = \frac{D_j - B}{abs(D_j - B) + A} + \frac{B}{B + A} \tag{4}$$

The above description only accounts for one period. Fishers confront a particular fish distribution on the Lake, act upon that, and they find a particular distribution that brings them to an equilibrium in which no boat wants to change their position and/or technology.

The conditions for the next fishing period, will no be the same, as the remaining stock, after fishing take place, will grow as a function of the overall size of it. This follows the standard assumptions in a Gordon-Schaefer model. There is an overall carrying capacity of the environment (Lake), and the growth follows the usual upside down curve, that implies faster growth rate for the mid range values of potential values of the stock. The overall growth of the stock depends on the overall remaining stock (after fishing). The starting stock distribution is assumed to be the natural one, so the new stock (remaining + growth) will use that initial distribution to assign relative weights to the stock at the start of the next period.

$$\dot{S} = \{\frac{S - \text{catch}}{K} - (\frac{S - \text{catch}}{K})^2\} * G \tag{5}$$

Fishers face this new density stock distribution, act upon it, and they find a new distributions of technology and effort that brings them to a new equilibrium in which no boats wants to change their position. This implies new decision on technology (t), numbers of boats at each location (n_j), and, consequently, new extraction levels (catch).

This process continues until the extractions levels are equal the growth rate.

3.2 The policy

This model is set with values to get an extraction level of approx. 20% of the overall biomass. This is in the actual range of current extraction in the Lake during one year. This is done by choosing the appropriate values for fixed costs, fuel cost and prices, as well as for the other parameters of the model. This sets the scenario for the open fishery, without regulations.

The model reproduces the fact that the most effort is done closer to the shores, and that most of the fish stock that is far away is not captured. This areas are not heavily fished but are also helping maintaining the overall stock. A policy that keep fishing out of these areas can be a potential intervention that helps stabilize the systems. It has potential advantages. It is easy(er) to enforce, as it does not require to check the gears, and it is confronting lower number of boats than those that have to be controlled in other areas closer to the shore. Enforcement levels can be choose depending on observable variables. With higher fish prices and lower fuel prices enforcement should be increased. With low fish prices and high fuel prices enforcement can be relaxed. This reduce enforcement costs.

Such policy does marginally reduce catch. It is clearly not enough to bring the system to an state of optimized revenues for the fishers. Nonetheless, this is a system already in a equilibrium, whose stability level is unknown. Can this policy make the system more stable? To have an initial answer to it, both scenarios are tested and compared as the two principal exogenous variables change: fish and fuel prices. Data from fish and fuel prices of the last few years were analyzed to get a measure of their variability. The range of both is similar so the system was tested, in both scenarios, with values ranging between 0.7 and 1.3 times of the initial scenarios for both fish and fuel price.

4 Results

The next figures (6 and 7) present the differences in boat distribution and type of technology for the basic scenario of the model. In the case of the restriction policy, a distance of 30Km was chosen as cut point. Note that as consequence of the policy, the central areas of the Lake are not suffering fishing pressure, but at the same time the number of boats in the allowed areas increase, which is the result of the increase in the stock density. Also important, it is that, under the policy, it is not only the multiple trips boats that are affected, reducing its area of operation, but also there is an increase in the boats using paddles, as with the increase in stock some areas are more profitable with those than with motor boats.

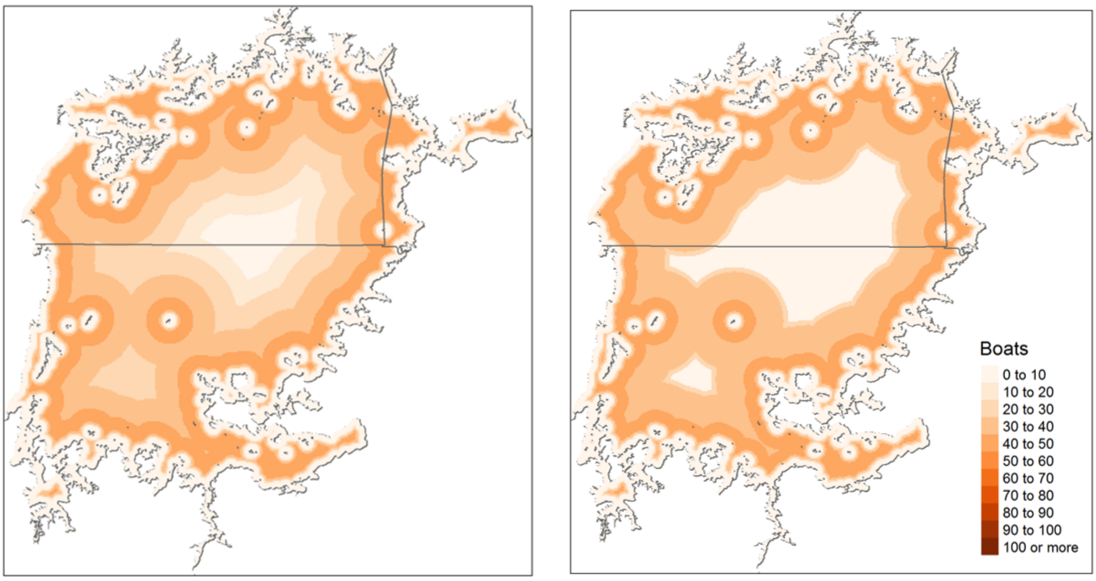

Figure 6: Boat distribution over the surface of Lake Victoria, baseline model. LEFT: full open access, RIGHT: Fishing restriction in the center of the Lake.

A total of 25 different combinations of fuel and fish prices, were employed to an equal amount of different scenarios with and without the restriction policy. The following table (1) reports the results for different variables in the overall data. We can see that the overall stock is higher under the policy and the effects are higher in the lower end of the

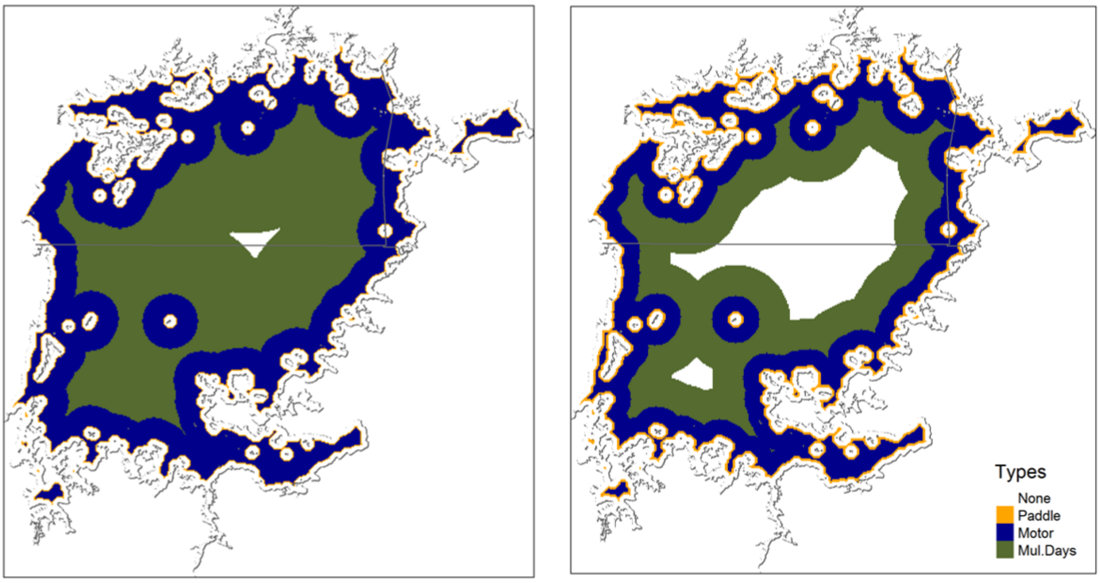

Figure 7: Boat type distribution over the surface of Lake Victoria, baseline model. LEFT: full open access, RIGHT: Fishing restriction in the center of the Lake.

stock where the differences are higher than in the higher end. Also the Stock variance, as measured by its standard deviation is clear higher in the open scenario. The situation is reversed in the level of Effort, which here it is measured as the number of boats in the Lake. Note that the relative differences in the amount of boats, between the presence of the policy and the absence of it, it is almost two times the relatives differences in the Stock between both scenarios. This is also the case with the catch. This translates to a Catch to Effort that is very similar in its mean value but that presents a clear decrease in variance under the active Policy, as measured by the standard deviation of this variable.

Taking the effort as the overall number of boats, disguises the dynamics of the different types of boats used in the Fishery. The biggest change occurs in paddle boats, that under the Policy are clearly more present than without it. This can be read in the mean values, and the max value that this variable can take. Nonetheless, although strongly affected, the number of paddle boats are relative few compared with the other two types of boats. Motor and Multiple days motor boats are both less numerous with the policy

Table 1: Outputs of the Model for 25 simulation along the spectrum of fish and fuel prices.

Output	Scenario	range	min	max	mean	sd
Stock	Open	22812	61315	84127	69717	8183
	Restricted	18264	66282	84546	73635	6701
Effort	Open	65872	516	66388	23282	20391
	Restricted	57766	91	57857	20184	18827
Catch	Open	17709	160	17869	6316	5405
	Restricted	16448	28	16476	5612	5181
Catch / Effort	Open	16.46	87.50	103.96	94.32	5.76
	Restricted	13.92	89.56	103.48	96.15	4.92
Effort (Paddle)	Open	113.22	0	113.22	7	23
	Restricted	707.3	0	707.3	142	230
Effort (Motor)	Open	11330.57	154.7	11485.27	4319	3127
	Restricted	10046.03	27.29	10073.32	3813	3236
Effort (Multiple)	Open	8431.16	0	8431.16	2659	3098
	Restricted	6576.58	0	6576.58	2101	2208
Tech. Concentration	Open	0.51	0.49	1.00	0.71	0.21
	Restricted	0.52	0.48	1.00	0.67	0.19

Notes: Overall results over the spectrum of simulations. Every simulation was run until reaching the and stable equilibrium.

in place but with stronger effects on the first one, both in terms of mean and variance.

Another way to look at it, it is using a diversity index for the composition of the fishing float (index: $\sum_t p_t^2$). In such a case, the policy implementation reduces the concentration and provides a more balance composition of the fishing fleet.

To get a sense of the enforcement required, in each case it is possible to calculate, in equilibrium, how many boats are not being allowed to fish in the restricted area. On average this is a 20% of the fishing fleet, but it can go up to being almost half of it, when fuel prices are in their lowest levels, and fish prices in the highest ones. It is also possible to demonstrate (not shown) that the Policy, although it always succeeds, it is more efficient, in the sense of being lest costly to each unitary increase in the catch, for lower values of fish prices and higher values of fuel. That is, when the incentives to increase pressure on the stock are not in their stronger version.

5 Discussion

The model proposed is able to replicate the main spatial characteristics of the Nile Perch Fishery in Lake Victoria. It is not yet set to replicate a full set of basic outputs of the system as it stand in the last years. That will be the purpose of a next iteration. Nonetheless, it can reproduce the basic dynamics of this system, and as such it is useful to get a first answer on the possibility of using spatial informed policies to help the management of the resource.

This first look at a policy that harness the added costs of reaching the more far away places on the Lake, it is informative. It has potential in reducing the variance of the system, particularly by increasing the lower levels of the stock that can be reached under a set of conditions, and allowing greater stability in the composition of the fleet. While far from being a overall solution, this could be part of a series of interventions that help in the overall management of the system.

6 Conclusion

Fisheries like Lake Victoria's Nile Perch face multiple challenges in their management. There is no enough governmental strength to bring the system to an optimal state that maximizes the profits to it users. This is due mainly to enforcement problems; but also to political economies under which a strong and sudden change to full control would necessarily expel a significant portion of the fishers from the activity. A measure that politicians are prone not to take into this type of development contexts. Sub-optimal policies still can have a place, as they could help the system maintain its balance. Avoiding the most deleterious of outcomes: a collapse of the system that would deprive of income thousands of people benefiting from the Fishery; also exposing them to severe negative impacts in their livelihoods.

Acknowledging the spatial structure of the Lake, and the consequences that it has to the Fishery, can provide another aspect that can be harnessed with management purposes. The case here presented have such potential, a restriction to fishing in the more far-from-the shores areas of the Lake reinforces the potential stabilization properties of the presence of lower fished areas in Lake Victoria. It also has the advantage that it does not create a completely new dynamic, and it provides an easier enforcement for patrols that are already operating in the Lake.

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