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Fishing Fleet Selectivity in Lake Victoria's Nile Perch Fishery.*

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Abstract

Current regulations regarding the Nile Perch Fishery in Lake Victoria provide gear specifications for the two main gears employed, Gillnets and Longlines, by defining the minimum size available. Additionally, the legal range of catchable fish is regulated: between 50 and 84 cm. Gillnets are legal over 5 inches, and the Hooks, required for Longlining, are legal from number 10 and below (lower numbers refer to higher sizes). Using data from the Catch Assessment Survey, CAS, we identify gear selectivity for Gillnets and Longlines. We use a novel methodology, that is validated using previous results for Gillnets for Lake Victoria. This is particular relevant as there is no much data for selectivity using Longlines. The information on selectivity is used to derive the overall fishing selectivity of the fleet. We find evidence of shift towards higher fish sizes in the Gillnet fleet, but a stagnation on fish sizes for the Longline fleet, even though there has been a compositional change in the hook sizes employed for this activity. The results signal towards a regulatory success among Gillnet users, but challenges in the regulation of Longliners.

Keywords: Gear Selectivity; Gillnets; Hooks; Nile Perch Fishery, Lake Victoria.

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1 Introduction

Fisheries management regulation in a *de facto* open access fisheries, as it is the case of Lake Victoria is a challenging endeavour. The sheer size of the fishery with over 77k boats actively fishing, the extension of the shore, 7.140 km (Hamilton, 2016), the dispersion of the fisher communities in many small landing sites, the dependence of communities in the outcomes of the fishery, and the political economy that does not allow to impose heavy entry regulation(Nunan, 2020) are issues that do not allow instruments as quotas or a cap on the number of boats to be used. Instead, much of the regulation in place relies on defining legal catch by its size. This is done by defining the legal outcomes (fish sizes between 50 and 85 centimeters) and legal inputs (which types of gear are allowed) for the activity (LVFO, 2016). In practice, most of the enforcement is done by enforcing the inputs.

There is an open discussion regarding the effectiveness of the enforcement in achieving the desired level of compliance (Cepić and Nunan, 2017; Obiero et al., 2015). Although this is extremely important, we think that it should be complemented with a proper discussion over the effectiveness of the regulation in achieving the desired effects on the Fishery. With that goal, this papers aims to provide information regarding the selectivity of the two man gears in the Nile Perch Fishery: Gillnets and Longlines (Hook method). And, building upon it, to present an overall picture of the fishing fleet selectivity in the Lake.

To do this, we use a novel method that make use of the rich data contained in the Catch Assessment Survey (CAS) (see (LVFO, 2015)), as the source for variation in the catch's size-profile as a function of gear size. This allows us to provide valuable estimations on the selectivity of Gillnets, but particularly on the selectivity of Longlines.

This text starts by presenting the two data set used for constructing, in a first step, the gear selectivity, and, in a second step, the fleet selectivity for years 2010 and 2020.

The method used to derive the Gillnet selectivity is first presented, and then the one to derive Longline selectivity levering on the results of Gillnets. Then the use of the Frame Survey to construct a fishing fleet selectivity is presented. The results follow. We found an absence of gradualism in the selectivity of Hooks, with changes that are only present to very small or very big hooks. Hooks that are either a bit bigger or smaller than the minimum legal size does not show differences in their average catch. This is not the case for Gillnets that are clearly catching bigger fish as the size of the gear increases. This implies that the regulation of Hooks it is not capable, even if fully enforced, the objectives of changing the catch's size-profile.

2 Methods

We start by describing the two main data sources, and then move to describe the three main procedures employed to derive: i) gillnet selectivity by gear, ii) hook selectivity by hooks size, and iii) overall fishing fleet selectivity in 2010 and 2020.

2.1 Data Sources

We used data from the Catch Assessment Survey, CAS (LVFO, 2020) from the years 2005 to 2015. This data set was designed to get a measure of the level of catch/effort in the fishery, and an approximation to the size of the catch. From a selection of Landing Sites around the Lake, enumerators at each location selected a sample of boats returning from fishing activities. From each boat, records of propulsion method, gears used, *total weight of the catch* and the *number of individual fish* are registered. These last two will be the key information to the analysis that we implement.

We used data from the Frame Survey for the years 2010 and 2020. This data set was designed to get a measure of the number of boats and gears that are active in Lake Victoria Fisheries. It is implemented as a complete census of all the active boats in the Fisheries including information regarding gear and propulsion. No data regarding catches is recorded.

2.2 Procedures

2.2.1 Gear Selectivity

Empirical Catch Distributions

The CAS data that we use as a source does not provide information relative to the individual fish and size distribution that are captured by a Boat. This individual fish level information is the normal information that is used to derive selectivity curves. Instead, we make use of the fact that there is a large number of observations recorded in the data set. As we want to focus on selectivity by gear, we start by filtering the data set to boat observations reporting only one type of gear and one gear size. This reduces the sample, but we still get a relative high number of observation. We get 27,774 observations, from which 16,549 are for Gillnets and 11,225 for Longlines.

For each one of the individual boat registers the average weight can be calculated, and, from it, the length value using the appropriate formula: weight $= a * \text{length}^b$, with $a = 0.0042$ and $b = 3.26$ (Yongo et al., 2017). Length values are classified in bins of one (1) centimeter, the floor function is applied to the range $[x, x+1)$ which is then classified as size x. All fish unit, by count, that correspond to the given value are assigned to this value. From this data a distribution of length is constructed for each gear and size combination in the data set.

As these distributions are constructed from average values from the catch, it is possible that a downward bias in the variance is produced. Note, that there is no bias in the mean value of the distribution, this is clearly identified. To validate the reliability of these distributions, two different paths were taken. First, a simulation of a fleet of boats capturing different number of individuals per trip were implemented to see the changes in the mean and variance of the sample as these happens (not shown here). Second, we directly compare the mean and the standard deviation that we construct from the CAS with the mean and the standard deviation of empirical experiments in which nets were thrown into the water and the size of each individual fish captured were measured.

Gillnets Selectivity

To derive the selectivity of Gillnets we make use of the Millar and Holst (1997). In this model we assume that the process that govern the number of fish encountering the net follows a Poisson distribution. For each length class L, the number of fish Y_{Lj} that encounter the net j (indexed by mesh size) are then:

$$Y_{Lj} \sim Po(i_j p_j \lambda_L) \tag{1}$$

Where i_j and p_j refer respectively to the fishing intensity and power of net j. And λ_L refers to the abundance of length class L. Then, the number of fish of length L that are caught in net j, are also distributed as a Poisson process (Millar and Holst, 1997), that also depends on the selection curve $r_j(.)$ of this net.

$$N_{Lj} \sim Po(i_j p_j \lambda_L \, r_j(L)) \tag{2}$$

We make the common assumption that the selection curve follows a normal distribution and that it also follows the principle of geometric similarity: the length of maximum retention and the spread of the selection curve are proportional to the mesh size (m_j) (Millar and Holst, 1997). This implies that the selection curve is defined as:

$$r_j(L) = exp(-\frac{(L - k_1 m_j)^2}{2k_2 m_j^2}) \tag{3}$$

The parameters that need to be estimated are k_1, k_2 and λ_L. Note that we know the intensity i_j because we known the relative abundance of the difference nets; and that we assume that p_j is the same for all the nets. That is, the probability of capturing the maximum retention size, if a fish of this size encounters the net, is the same irrespective of the particular size j. We end fitting the following equation, using Maximum Likelihood techniques in R (R Core Team, 2021).

$$log(V_{Lj}) = log(i_j) + log(p_j) + log(\lambda_L) - \frac{(L - k_1 m_j)^2}{2k_2 m_j^2} + u_{Lj} \tag{4}$$

From which we can recover the required parameters.

Longlines Selectivity

Retrieving selectivity for Longlines is a more difficult challenge. The most notable result is that there is no evidence in the data that changes in hook size correspond with changes in average size, except for the bigger hooks sizes (i.e., those with smaller numbers).

As a consequence, a more data driven procedure was employed. As an outcome of the modelling to calculate gillnet selectivity we get estimates of the relative frequency of the stock at each size λ_L. We calculate the empirical distribution of the catch using Hooks of different sizes (N_j), and use the estimated stock distribution to obtain the implied selectivity of the hooks.

$$N_{Lj} = r_j(L) * \lambda_L \tag{5}$$

Note, that these do not require to have a overall estimation of the total mass or effort that is applied with a gear, but only the relative catch per size class, and the relative frequency per size class as well.

$$r_j(L) = \frac{N_{Lj}}{\lambda_L} \tag{6}$$

2.2.2 Fishing Fleet Selectivity

One important goal is to use the data on selectivity to derive the overall selectivity of the fleet. To being able to do that two requisites are needed. First, data on the relative proportion of the different gear-sizes pairs are needed. Second, a conversion factor is needed to being able to compare Longlines with Gillnets. Note that Gillnets of different sizes can be combined by assuming that two of different sizes are equivalent in the sense that when in contact with their preferred size fish the probability of capture is the same, that is their fishing power is identical. We do not observe this, but given that they are identical in every respect but size, this is a reasonable assumption. With Hooks of different sizes the reasoning is equivalent. What it is not clear is how to compare Hooks with Gillnets. There is no information regarding this, which ideally will take the form of exposing a gillnet and a hook that select for the same size to the same fish stock, and recording their catch differentials.

To circumvent this problem, we will compare the catch of gillnets and hooks that are selecting for the same size. We use the average catch of each gear and apply a correction factor cf that brings the number of one gear in terms of the other. We are answering the question: *how many gears of type B, that select for size H, are needed to apply the same effort, and hence provide the same output, than gears of type A that select for the same size?.*

With this factor it is then possible to construct an overall fish selectivity $R(.)$, that is composed by weighted aggregation of the selectivity of each gear. The weights reflects the relative abundance of each gear size. The overall selectivity is standardized to be one (1) at the size of maximum retention.

$$R(L) = \frac{1}{\sum w(g)_j + \sum w(h)_j} \{ \sum_{\text{gillnets}} w(g)_j * r_j(L) + \text{cf} \sum_{\text{hooks}} w(h)_j * r_j(L) \} \qquad (7)$$

3 Results

3.1 Empirical Catch Distributions

The next table, 1, presents the results of comparing data on experimental catches that count and weight every fish that is caught, with the empirical distribution that we get out of the CAS (see also figure 1). Note, that recorded means are very similar. and that the standard deviation is higher on the experimental data.

	Experimental		CAS	
Gill Net Size (Inches)	Mean	St. dev.	Mean	St. dev.
3	27.2	5.6	27.2	5.6
4	35.8	8.0	38.0	7.8
5	42.3	9.6	47.2	6.9
6	51.2	13.1	53.8	6.7
7	55.3	18.9	57.6	6.0
8	62.2	15.0	63.1	13.1

Table 1: Gillnets. Mean and Std.dev. of empirical catches by size. The experimental information comes from LVFO, 2021 (original data was collected circa 1996).

Figure 1, allows to compare the data that comes from the Gillnets, left, with the data from Hooks, right. The differential height of the data coming from different size clases within each gear is due to both the differential numbers of fish at each size, and also, more strongly, to the differential number of boat at each gear size-class that are recorded in the dataset. Importantly, note that Gillnets have a clear variance in the location of the curve, particularly the location of the maximum size-class catch. With gear of larger sizes having a larger value. This is not the case for Hooks, the most immediate difference relies on the height of the distribution but not on its location (as attested by the position of the maximum size-class catch).

3.2 Gear Selectivity

We used formula 4 to retrieve the parameters that define, given the assumptions described in the methods, the selectivity of the gear. We get that the parameters $k_1 = 3.75$

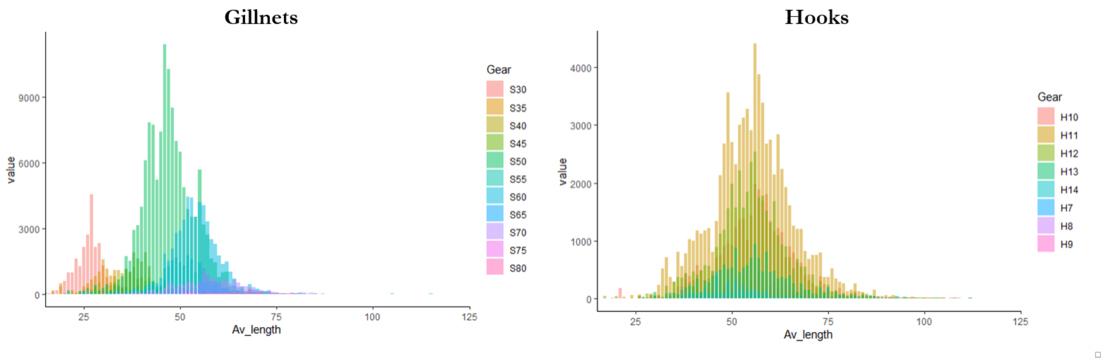

Figure 1: Empirical Catches using gillnets and hooks of different sizes. The y axis refert to the total amount of individuals in the sample used to generate the graphs (refer to the text for more details).

and $k_2 = 0.387$, we use them to retrieve the gear selectivity that it is shown in figure 2, left panel. This method also delivers an estimation of the stock distribution, using as info the differential levels of average total catch per net size. Figure 2, right panel.

Note there is necessarily a difference between the selectivity and the catch. The maximum retention of a particular gear size is not necessarily the higher catch that the gear would get. The stock distribution can make the lower sized fish to be far more common. This can be seen in figure 3, which compares the selectivity curves, the implied expected catch distribution (given the stock distribution estimation), and the empirically observed catch distribution. Note that the difference between selectivity and expected catch grows with the increases in mesh size (see Kolding et al. (2016)).

As exposed in the previous section, a similar analysis is not possible to implement with the Hook data. The method assumes and requires an increase in maximum retention sizes as the size of the gear increases, this is not true for data on Hooks sizes. The more data driven approach previously described was implemented. Using as a input the stock distribution that was retrieved from the processing of the Gillnets. Figure 4 shows the results of that processing. Note that there is an important overlap for much of the class size between hooks number 10 to 14. Size number 9 is quite similar to the previous ones,

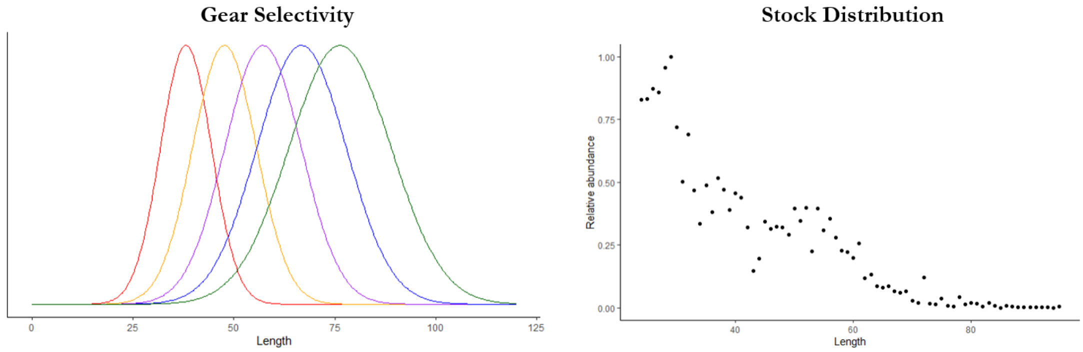

Figure 2: **Gillnet selectivity and Stock relative frequencies**. This figure present the result of the gillnet selectivity estimations. As is standard with selectivity curves, the size of maximum retention is standardize to one (1). The same is being made with the values for abundance of size class.

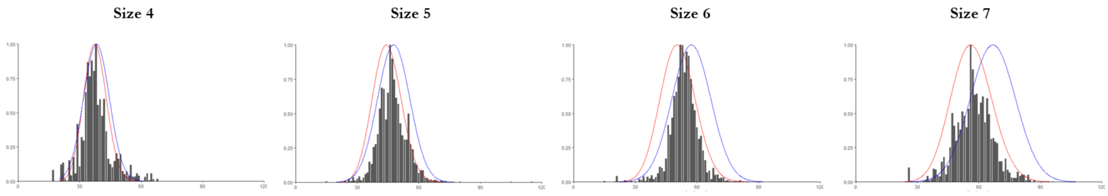

Figure 3: **Gillnet selectivity and observed catch**. The blue line shows the estimated selectivity by size, the red one, the estimated catch using the estimation about the stock distribution. The grey bars show the underlying data. Everything is standardized to one at the maximum.

but also has a fat tail to the right. Size number 7 is clearly directed toward bigger fish.

There was not enough data for hooks of number 8 to be calculated.

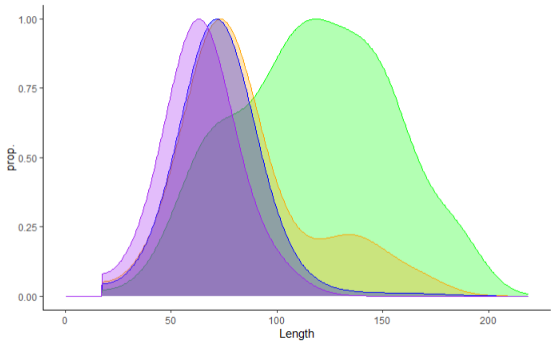

Figure 4: Hooks selectivity, results using estimations for stock distribution from the Gillnet data. Purple refers to size 14, blue to sizes 13 to 10, Yellow to size 9, and Green to size 7.

3.3 Fishing Fleet Selectivity

We used the data coming from the Frame survey to get a proportional count on the number of gillnets and hooks by size at two points in time 2010 and 2020. We use that info to aggregate the selectivity by each size class, into an overall fishing fleet selectivity. Figure 5 present the results from it. The left column presents the results for the selectivity, and the right column the predicted catch distribution, given the derived stock. Top to bottom, there are the graphs for Longlines fleet, Gillnet fleet and Longlines and Gillnet fleet together.

Note that there is a decrease between 2020 and 2010, of the relative number of boats using higher sized hooks (low numbers). See the two top graphs in figure 5. This does not translate into a big chance in the selectivity curve, due to the change taking place between hooks that are not capturing radically different fish sizes. This is more readily seen as the expected empirical catches do not have a discernible change betwen the two periods. This is not the case for Gillnets. See the two middle graphs in figure 5. There is a decrease in the catch selectivity for lower sizes, that it is even more evident in the empirical catch. This is the result of a change to higher gillnet sizes that is quite noticeable in the data.

When the overall fishing fleet selectivity is considered, there changes are mainly due to the changes coming from the Gillnets selectivity changes. The Longline fleet increases the catches for bigger sizes in both periods. This come for a higher maximum selection size and a wider selectivity across the range for the case of the Hooks.

4 Discussion

The results for the Gillnet selectivity are in line with what can be found in similar studies. This is not the case for the Hooks. Where there is a change in the maximum retention size only for the higher and the lower hooks sizes (number 14 and 7), all the rest

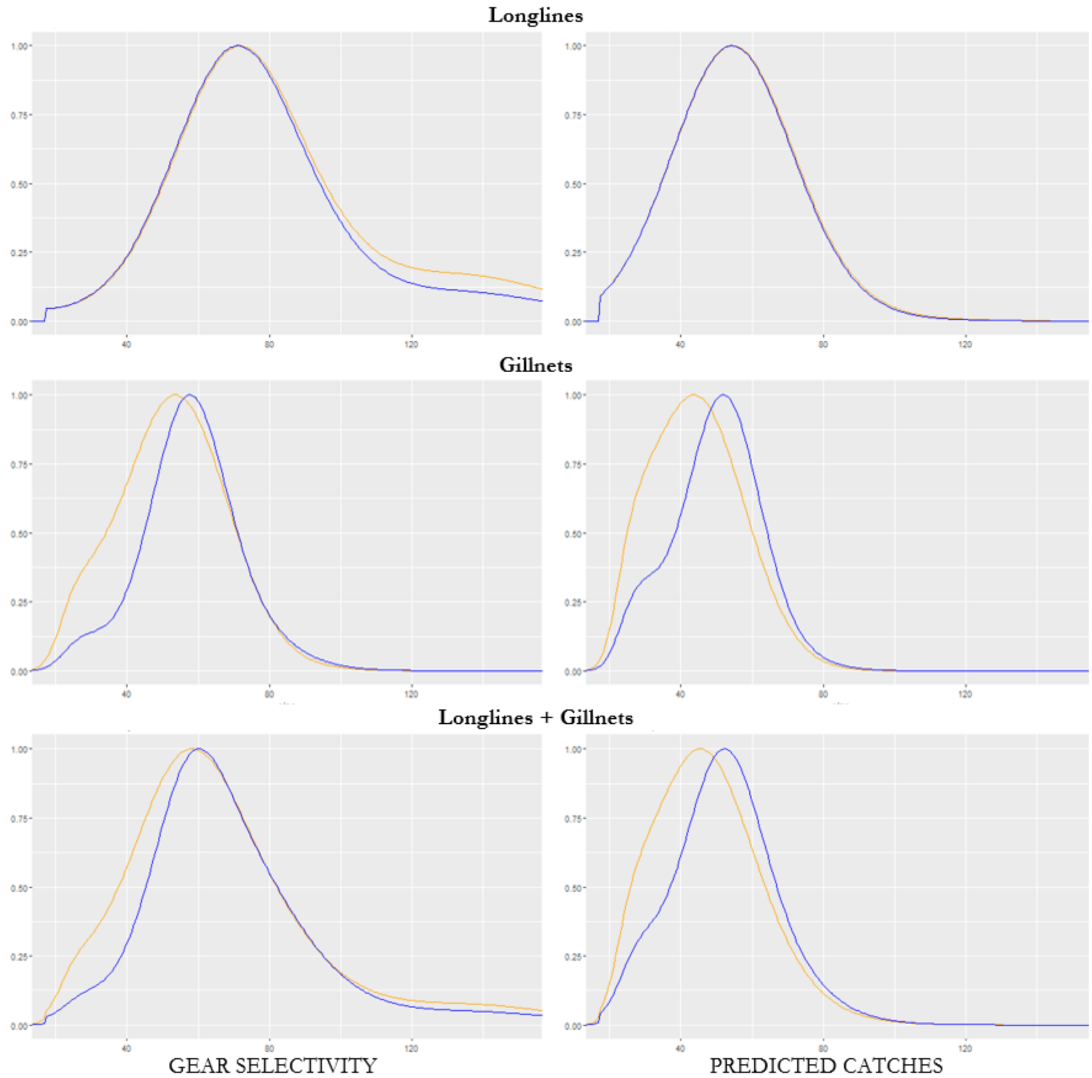

Figure 5: **Fishing Fleet Selectivity, 2010 and 2020**. Curves of fleet selectivity, and empirical catch distribution by type of gear and overall. Blue curves: 2020, Yellow curves: 2010.

are indicating very similar selectivity. One possible confounding factor is the absence of information regarding the bait. Note that the even in the absence of bait information, a preliminary hypothesis can be made. Mainly, that bait is a far greater determiner of size selectivity with hooks than hook size alone (Mkumbo and Mlaponi, 2007). This is congruent with what is known about the role of bait in hook fishing.

The other important result is the higher size selectivity of Hooks vs Gillnets. One

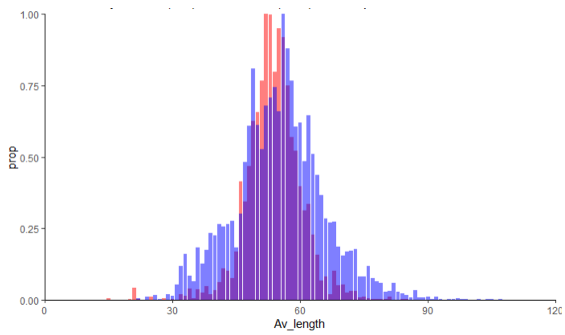

Figure 6: Empirical Catches, comparison between Gillnet gear one size **above** legal size, and Hooks from Longlines one step **below** legal size. Both catches are *on average* the same. To facilitate the comparison both are scaled to be one (1) at the highest catch level.

important factor is the fact that boats with undersized hooks (according to regulation) catch fish that is roughly equivalent in their size distribution to legal size gillnets. This is shown in Figure 6, that depict the empirical distribution obtained from Gillnet of size 6 (one inch higher that the minimum allowed gillnet size), and Hooks of size 11 (one step below the minimum allowed hook size)[1]. This translates in an overall higher size selectivity for the Longline fleet over the Gillnet fleet.

It is important to notice that the data and the results obtained with this procedures are assuming, on average, that every boat is facing the same stock distribution. That is, that boats cannot purposely fish in areas that have higher concentration of fish within a particular category. This can be a potential concern for the data from Hooks. A better way to understand this, it is to think in selectivity as the outcome of both the proper selectivity of the gear, and the added effect of the behavior of the fishers regarding the choosing of fishing areas. Even in such a case, one results is clear: fishers using undersized hooks are catching a higher sizes of fish that those using minimum legal net mesh sizes.

The data processed here is not intended to get a direct measure of the size of the stock. That is, how many tons of Nile Perch, and what is the size of the remaining stock.

[1]There are, in any case, no discernible differences between hooks of size 10, 11, 12, and 13.

Although work in that direction could be potentially be feasible, that is not within the scope of the present paper.

5 Conclusions

The present paper presents the results of a novel analysis of the two main selectivity gears in the Nile Perch Fishery in Lake Victoria. This analysis relies on a rich dataset, and on procedures that leverage the absence on per boat detailed per fish data, using a high number of observations. This analysis allows to derive measures for the gear selectivity but also estimations on the stock size distribution faced by fishers.

One immediate consequence of the analysis relates to the status of the current regulation regarding fishing gear for the Nile Perch. Data from the Frame Survey attests that while the compliance with the gear regulation has increased, the compliance with the Hook regulation has not. Our results helps to give nuance to this finding. Gillnet regulation seem to work in the intended direction. Restricting the gillnet mesh size to a minimum size also restricts the catch of smaller fish.

Hook regulation does not seem to have an effect. Even in the case that the regulation had been followed, the data from the selectivity imply that there would be no change in the catch. If the goal is to use hook size restriction as a useful management strategy (see Chitamwebwa et al. (2009)), restrictions should be placed allowing only the smaller size in use (number 14) to be legal. Nonetheless, even then, the change in average size are not comparable with the changes that are forced in selectivity by forcing changes in Gillnet mesh sizes.

Particular attention must be given to the fact that even with an, in practical terms, unregulated Longline fleet, this fishery is getting larger fish sizes as compared to the Gillnet fleet, which has a higher compliance with existing regulation. Hook regulation does not, in light of these findings, have the ability to produce the desired outcome changes in the profile of fish size that are captured using Longlines.

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