Rebuilding Kenya's freshwater fisheries catch datasets: 1950-2017

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Abstract

Globally, most reported freshwater catches come from developing countries where freshwater fish underpin local food security and livelihoods. To ensure sustainable management of freshwater fisheries, accurate catch data are needed to support fisheries management authorities in developing countries. However, freshwater fisheries catch data reported by the FAO on behalf of countries globally under-represent small-scale fishing sectors, and have low taxonomic and spatial resolution. Kenya is a developing country with a socio-economically important freshwater fishery and declining freshwater catches over the past two decades. A reconstruction of freshwater fisheries catch data for Kenya between 1950 and 2017 was undertaken to improve upon the accuracy of existing reported catch datasets and to provide a more ecologically and spatially relevant dataset for research and management uses in Kenya and globally. A comprehensive time series of catch for 16 waterbodies in Kenya was produced, based on a thorough review of secondary data and information sources and in collaboration with experts on Kenya’s fisheries. Total reconstructed catches between 1950 and 2017 were 1.9 million tonnes, or 32%, higher than those reported on behalf of Kenya by the FAO. The subsistence sector accounted for 71% of unreported catches, indicating catches for local consumption are greatly under-represented in nationally reported statistics and should receive greater attention from management to support food security in Kenya. The results of this study provide a template for future freshwater catch reconstructions and contribute to a better understanding the importance of freshwater fisheries for local food security in developing countries.

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1. Introduction

1.1. Global freshwater capture fisheries

Global freshwater capture fisheries are an important source of affordable animal protein in developing countries and support over 60 million jobs (FAO 2020a). Despite this, freshwater fisheries receive little attention in global fisheries research and management when compared to their marine counterparts. Freshwater fisheries are thought to account for approximately 12% of global reported catches, of which 90% comes from developing countries, particularly in Asia and Africa (Bartley et al. 2015, FAO 2020a). The small-scale nature of most freshwater fisheries results in high levels of local catch consumption, with relatively low discards and little high-grading of catches (Coates 1995, Funge-Smith and Bennet 2018, Funge-Smith and Bennet 2019). These trends lead to high levels of local fisheries-related employment, providing an income as well as a nutritious food source for people in low socio-economic and often marginalized populations, including women and children (Coates 1995, The World Bank 2012, Funge-Smith 2018). High levels of local consumption of freshwater catch, particularly in low GDP countries that have relatively low levels of *per capita* animal protein consumption, means that freshwater fish are able to provide more dietary protein and nutrients, per tonne, than marine or aquaculture-produced fish (Funge-Smith 2018, Funge-Smith and Bennett 2019).

1.2. Freshwater fisheries statistics

It is widely believed that freshwater fisheries catch data reported to the FAO (Food and Agriculture Organization of the United Nations) is unreliable and likely grossly underestimates the true contribution of freshwater fisheries to global capture fisheries (Coates 1995, Welcomme 2011, Bartley et al. 2015). The poor quality of freshwater catch data reported to the FAO by countries globally is thus reflected in the data that the FAO reports. Only 25% of freshwater catches are taxonomically identified to species level in freshwater fisheries compared to approximately 60% in marine fisheries (Pauly and Palomares 2005, Bartley et al. 2015). Large historical reclassifications of data have occurred between the aquaculture to the wild-capture sector (Bartley et al. 2015). Catch data do not differentiate between waterbodies, making the total catch and taxonomic breakdown of catch for a given country relatively uninformative as an indicator of freshwater fisheries and ecosystem status or health at a spatially relevant level. National fisheries bodies may have data differentiated by waterbody, but the FAO requests data only by country and FAO area. National catch data are often only collected at commercially important landing sites and therefore catch from other sectors, particularly the subsistence (i.e., small-scale non-commercial) and recreational ones, is often not included in national statistics despite often accounting for an equal, if not larger weight of catch than the commercial sector (Welcomme 2011).

Accurate and detailed fisheries statistics are a foundational resource for the sustainable management of freshwater ecosystems and the fisheries they support. Catch data are the cheapest and easiest fisheries data type to collect, and therefore are of particular importance in developing countries that often have extremely limited resources for fisheries science and management (Kleisner et al. 2013). Data-limited stock assessment methods (e.g., Froese et al. 2017, 2018, 2019), for which catch data are a fundamental part, are often the only available method to assess the status of fish populations in developing countries. Thus, improving the accuracy and resolution of historical catches for freshwater fisheries can be highly beneficial and useful for in developing countries.

1.3. Re-estimating catches for global freshwater fisheries

Several studies have demonstrated deficiencies in freshwater catch data through re-estimating total global or total regional freshwater catches. Re-estimations have involved using proxies for catch, such as average yield per aquatic habitat type (Lymer et al. 2016), average household freshwater fish consumption (Fluet-Chouinard et al. 2018), satellite-derived estimates of lake chlorophyll concentrations, among others (The World Bank 2012), to calculate total single-year global catch estimates. Estimates produced in these studies indicate that global freshwater catches could be up to 650% larger than reported by the FAO. Global total reconstructed marine catches for 2016, for example, are just 35% higher than reported by the FAO. Therefore, the unreported component of global freshwater catches may be proportionally much larger than marine catches.

Re-estimates of catch are useful for demonstrating the need for improvements in freshwater catch data but they are of limited use for fisheries and ecosystem management. Previous re-estimates of catch for freshwater fisheries have primarily focused on producing single year estimates of catch. Without considering misreporting of catch historically, it is not possible to produce more realistic catch trends which can be useful for informing ecosystem and fisheries management. Additionally, these estimates of global freshwater catch do not allocate catch to taxonomic groups or specific waterbodies. Historical reconstructions of catch time series undertaken on a country-by country basis and utilizing secondary data sources can produce high resolution catch data that includes allocation of catch at a spatial, sectoral and taxonomic level, as demonstrated for marine fisheries by Pauly and Zeller (2016a, 2016b). This empowers detailed examination of historical catch trends that are useful for fisheries and ecosystem management. Such catch reconstructions for freshwater fisheries have not been undertaken to date, with this study presenting the first such estimate for Kenya.

1.4. Kenya’s fisheries

Kenya is classified as a developing country (United Nations 2019) and has a rapidly growing population of over 50 million (The World Bank 2019). Food security issues are prevalent throughout the country (Kimani-Murage et al. 2011), including widespread malnutrition and micronutrient deficiencies (Siekmann et al. 2003, CAADP 2013). Capture fisheries play a central role in Kenya’s culture, economy and food supply chain, and were valued at US$440 million in 2018, with approximately 1.2 million people directly or indirectly employed in fisheries (KMFRI 2018). Compared to many other coastal countries, Kenya’s capture fisheries are unique in that more than 75% of total annual reported national catches come from freshwaters (FAO 2020c).

Figure 1. Map of Kenya’s major freshwater bodies. Source: Shuttershock.

Lake Victoria, with 6% of its 68,800 km^2 area in Kenya (Fig. 1), is the second largest lake in the world. Its fishery provides East Africa's most important source of affordable animal protein, with catches from its waters used for domestic consumption and international export (Cowx et al. 2003, KMFRI 2018). Lake Victoria's largely open access fishery dominates Kenya's reported catches, accounting for up to 97% of Kenya's total annual reported freshwater catches and up to 95% of total annual reported national catches from marine and freshwaters (KDF 2016, FAO 2020b). From the 1950s to the 1970s, Kenya's portion of Lake Victoria supported a diverse fishery, with native haplochromines and native tilapias accounting for a large portion of catches (Ogutu-Ohwayo 1990, Aura et al. 2020). From the 1980s to present, the introduced Nile perch (*Lates niloctilus*), native silver cyprinid (*Rastrineobola argentea*) and introduced Nile tilapia (*Oreochromis niloctilus*) have dominated reported catches.

A multi-million dollar export industry for Nile perch developed in the 1980s and persists to the present day, with developed countries such as Israel and those in the European Union the primary destinations of these exports (Cowx et al. 2003). Since the 1990s, up to 65% of annual reported silver cyprinid catches from Kenya's Lake Victoria fishery have been converted to fishmeal for animal feed (Abila 2003). Consequently, the proportion of catch across Lake Victoria that has gone to local food supply has declined from approximately 80% in 1980 to 20% in the 2000s (Muyodi et al. 2010). The high prices paid by fishmeal and Nile perch processing factories, alongside declining catches, have inflated fish prices over the past three decades, making high quality fish unaffordable for most locals (Abila 2003, KMFRI 2018). High fish prices have provided an opening in the market for cheap and low quality aquaculture-produced fish imports from China (Dijkstra 2019). These imports have increased rapidly since 2017 and have undercut locally caught fish at market, negatively effecting the incomes and livelihoods of Kenyan fishers.

Lake Turkana (Figure 1), formerly known as Lake Rudolf, supports Kenya's second largest freshwater fishery, accounting for approximately 5% of reported freshwater catches over the last decade (KMFRI 2018). Eight other lakes, dams or rivers that support fisheries are included in nationally reported data, with reported catches from these collectively accounting for approximately 1% of reported freshwater catches over the past decade. The fisheries of Lake Turkana and other smaller freshwater bodies in Kenya are primarily open access, with catches primarily consumed domestically (KMFRI 2018).

Fish is likely to become a more important part of Kenyan diets in the future. The Kenyan government, as part of its Kenya Vision 2030 long-term development blueprint (Government of Kenya 2020), aims to raise the national *per capita* fish consumption rate from 4.7 kg/year to the African average of 10 kg by 2030 (KMFRI 2018). Given the large portion of Kenya's reported catches that come from freshwaters, effective management of freshwater fisheries will likely play an important role in supporting future fish consumption increases.

Catch data collection is particularly challenging in Kenya due to a number of factors. These include the over 300 catch landing sites on Kenya's shores of Lake Victoria alone (KMFRI 2018), dominance of small-scale fishing sectors and large number of freshwater bodies with fisheries throughout the country (Cowx et al. 2003). Additionally, fisheries contribute relatively little to Kenya's GDP (~0.5%) and are therefore not viewed as a national priority, leading to a lack of investment in monitoring and assessment nationwide (Tuda 2018). This is reflected in the limited number of stock assessments conducted for freshwater fish stocks in Kenya. Stock assessments have been conducted for fish stocks in just four freshwater bodies in Kenya: Lake Victoria (Kayanda et al. 2010), Turkana (Kolding 1995), Baringo (Macharia et al. 2017) and Naivasha (Hickley et al. 2002). The Kenya government has outlined the improvement of stock assessments and setting of reference points as a key element of the country's long-term development blueprint (Government of Kenya 2020). Thus, improving the accuracy and reliability of Kenya's freshwater catch data is essential for effective management to support food security.

Kenya's marine fisheries data were the subject of two catch reconstructions by the *Sea Around Us* initiative, covering the period 1950-2018 (Le Manach et al. 2016, McAlpine 2019). Reconstructed catches from these studies revealed that 160% of catches were not reported in FAO data, and catches from small-scale sectors were under-represented.

1.5. Aims

This study had two central aims: (i) to produce a high-quality catch dataset for Kenya's freshwater fisheries, disaggregated by waterbody, sector, taxa and reporting status; (ii) to provide an initial evaluation of these newly derived data. These data will provide a more accurate historical baseline of catch that can be used support the assessment of freshwater fisheries and ecosystems in Kenya, while also demonstrating the need for improved freshwater catch data on a national, regional and global level. As the first catch reconstruction of a country's freshwater fisheries, this study will help facilitate future freshwater catch reconstructions to be undertaken by the *Sea Around Us* initiative to compliment those completed for global marine fisheries (Pauly and Zeller 2016a, 2016b).

2. Methodology

The general methodology of this study followed the established catch reconstruction approach first applied for Pacific Islands in Zeller et al. (2006, 2007), described in Zeller et al. (2016) and applied globally for marine fisheries (Pauly and Zeller 2016a, 2016b). This approach uses official reported data as baselines, and complements these with estimates of unreported catches based on secondary information and data sources, in addition to consultation with in-country fisheries experts. Only landed (i.e. retained) catches for Kenya were addressed in this study as discards from small-scale sectors, which dominate Kenya's freshwater fisheries, are thought to be minimal or low (Zeller et al. 2018).

2.1. Establishing baseline data

The State Department for Fisheries, Aquaculture and the Blue Economy, also known as the Kenya Department of Fisheries (herein referred to as the KDF), is responsible for collecting and reporting fisheries data in Kenya. Catch data reported by the KDF were obtained from various Kenyan government and FAO reports, as well as unpublished data provided by in-country collaborators (Appendix Tables A1-A9). National freshwater catch data reported by the KDF, which covers the years 1967-2017, were compared with data reported on behalf of Kenya by the FAO (FAO 2020c), which covers the years 1950-2018. Data reported by the KDF separates catch by several waterbodies and has a higher taxonomic resolution of catch than FAO reported data, which does not separate catch by waterbody. The KDF reported catch data were employed as the baseline for this reconstruction to enable the production of a catch time series separated by waterbody that was of greater spatial, ecological and fisheries-policy relevance than FAO reported data. This approach was also chosen to mirror the marine catch reconstructions of the *Sea Around Us* which improved upon the spatial resolution of FAO catches by allocating catches to exclusive economic zones (Pauly and Zeller 2016a, 2016b). The final year of 2017 was chosen for this study as it was the most recent year for which catch data reported by the KDF was available. The FAO dataset (FAO 2020c) does cover 2018, but the 2018 data for Kenya is a preliminary FAO estimate (James Geehan, FAO Fisheries Statistician, pers. comm.) and was therefore not used to produce reconstructed catches for 2018.

2.2. Spatially allocating catch

The number of waterbodies that KDF reported catches are assigned to differs historically. The most recent KDF reported catches for 2017 are separated by 10 waterbodies and an aggregate category labelled 'Riverine.' The number of waterbodies reported in KDF data declines to just four prior to 1990, with additional catches assigned to an aggregate category labelled 'Other'. No information was included as to which waterbodies the 'Riverine' or 'Other' catch came from (KNBS 1972, KDF 2017).

Through an extensive review of the secondary literature, and in collaboration with several experts on Kenya's freshwater fisheries, six freshwater bodies with known fisheries from 1950-2017, but not included in KDF data, were identified. Through this literature review, historical fisheries information for specific years and/or sectors, i.e. anchor points, were identified for these six waterbodies. For the 10 waterbodies reported in KDF data, anchor points were identified for the time periods in which no catch data was reported and for sources of unreported catches. Anchor points included estimates of catch (reported or unreported), taxonomic compositions of catch and numbers of licensed fishers (Appendix Tables A1-A9).

The 16 waterbodies were then grouped into three categories based on the quality and quantity of anchor points and baseline data available (Table 1):

- 'Lake Victoria': this category included Lake Victoria alone, which had totals and taxonomic compositions of catch, in addition to numbers of licensed fishers available for 1968-2017, with limited information prior to this (Appendix Table A1).
- 'Lakes, dams and the Tana River Delta (TRD)': A total of nine waterbodies were placed in this category. Totals and taxonomic compositions of catch were available from 1992-2017. Some information was available from 1967-1991 but as mainly as catch totals and very limited information prior to this (Appendix Tables A2-A8). Lake Jipe, Lake Chala and other waterbodies in Taita-Taveta county were reported collectively in KDF catch data from 1992-2017 without any information included regarding the proportions of catches for which each of these waterbodies accounted for. Therefore, these waterbodies were grouped together for the purposes of this study.
- 'Rivers': the six waterbodies placed in this category were not included in nationally reported KDF data. Very limited fisheries information, in the form of catch totals only, was available from 1950-2017 (Appendix Table A9).

Table 1. Waterbodies included in this study, with the category they were assigned to and their associated county or province for which population data was used. Population data was not needed for all waterbodies from 1950-2017, thus only the years for which population data was used are listed. TRD= Tana River Delta. Source: KNBS (1957, 1967, 1974, 1982, 1994, 2002, 2012, 2019).

Category	Waterbody	Year/s	County/province used for population data
Lake Victoria	Lake Victoria	1989-2017	Nyanza province
Lakes, dams and TRD	Lake Turkana	1948	Northern Frontier province
		1962-1999	Turkana and Marasabit counties
		2009	Turkana Central and Marasabit counties
	Lake Baringo	1948-1999	Baringo county
		2009-2017	Baringo and Baringo North counties
	Lake Naivasha	1948	Nakuru county
		1962	Naivasha county
		1969-2017	Nakuru county
	Tana river dams	1989-2017	Embu and Machakos counties
	Tana river delta	1948	Tana-Lamu county
		1962-1999	Tana county
		2009-2017	Tana delta county
	Turkwel dam	1948	Nyanza province
		1962-1999	West Pokot county
	Lake Kanyaboli	1948-1962	Nyanza province
		1969-2017	Siaya county
	Lake Kenyatta	1948	Tana-Lamu county
		1962-2017	Lamu county
	Lake Jipe, Lake Chala and other fisheries in Taita-Taveta county	1948-2017	Taita-Taveta county
Rivers	Sondu-Miriu river	1948-1962	Central Nyanza county
		1969-1989	Kisumu county
		1999-2017	Kisumu and Homa Bay counties
	Kuja river	1948-1962	Nyanza province
	Athi-Sabaki river	1948-1962	Kilifi county
	Malewa river	1948	Nakuru county
		1962	Naivasha county
		1969-1989	Nakuru county
	Nzoia river	1948-1962	Nyanza province
	Ewaso-Ngiro river and swamp	1948-1962	Northern province

2.3. Producing full time series of baseline catches

A total baseline time series of catch for Lake Victoria was produced by linearly interpolating between years with catch anchor points (Appendix Table A1). A partial time series of baseline catches were produced for all waterbodies in the 'Lakes, dams and TRD' through interpolation between anchor points (Appendix Tables A2-A8). It was not possible to produce catch estimates for the earliest parts of the time series (i.e., closest to 1950) via linear interpolation between anchor points as no catch anchor points were available for, or prior to, 1950 for waterbodies in the 'Lakes, dams and TRD' category (Appendix Tables A2-A8). This was also the case for waterbodies in the 'Rivers' category (Appendix Table A9). An alternative method of estimating catch was required as no information was identified in the literature that suggested fishing in waterbodies from the 'Lakes, dams and TRD' or 'Rivers' categories was not occurring prior to 1950 (with the exceptions of Lake Baringo, Turkwel Dam and Tana River Dams, see Appendix Table A10 for a more detailed explanation).

Water levels are known to be closely correlated to catches in freshwater bodies in Kenya (Gownaris et al. 2017), but no continuous water level data was available for any of the waterbodies included in this study. Catches were estimated back to 1950 by assuming catches changed at the rate of change of population density (persons/ km^2) in the county/province in which the waterbody was located (Table 1, see Appendix Table A11 for a more detailed explanation). Population densities for each county/province data were taken from historical Kenyan censuses (KNBS 1957, 1967, 1974, 1982, 1994, 2002, 2012, 2019) and linearly interpolated between these years to produce a total time series of population density for each county/province. Where a waterbody spanned over two counties, the mean population density of the two was used. Population densities for each county/province decreased back to 1950, meaning reconstructed catches for waterbodies without catch anchor points for, or prior to, 1950 also declined back to 1950. Thus, catches estimates produced via this method are likely conservative. This method was based on the well-established method described in Pauly and Zeller (2016a). Population density was the primary continuously recorded human population indicator available for each county/province from 1950-2017 and was used instead of total population as the size of the counties/provinces changed between census years.

Waterbodies in the 'Rivers' category did not have catch data available after 1990 (Appendix Table A9). Catches were estimated from the latest catch anchor point (i.e., closest to 2017) forward to 2017 based alternative fisheries information and trends in catch from geographically similar Kenyan waterbodies with catch anchor points available for 2017 (See Appendix Table A10 for detailed explanations).

Lake Victoria and all the waterbodies in 'Lakes, dams and TRD' category did not have taxonomic composition anchor points of catch for or prior to 1950 (Appendix Tables A1-8). The taxonomic composition of catch from the earliest anchor point available for each waterbody was applied to all catches preceding it (See Appendix Table A11 for a more detailed explanation). Where there were gaps in the taxonomic compositions of catch between anchor points, the proportion of total catches for each taxonomic group was linearly interpolated between anchor points. Species from the genus *Protopterus* were introduced into Lake Baringo in 1975 and were known to first appear in reported catches in 1984 (KMFRI 2018). As no taxonomic composition for reported catch was available for 1984, the proportion of catches from Lake Baringo that these species accounted for was assumed to be 0% in 1983 and was assumed to increase linearly to the next anchor point for taxonomic composition in 1992. The introductions of Nile perch and Nile tilapia into Lake Victoria are accounted for in reported data. No taxonomic compositions of catch were available for waterbodies in the 'Rivers' category, therefore all catches were categorised as 'Freshwater fishes not elsewhere included.'

2.4. Producing full time series of unreported catches

2.4.1. Fisher-household catches

There was no information identified in KDF reports, the secondary literature or through correspondence with Kenyan freshwater fisheries experts that suggested subsistence catches were included in total catch estimates for any waterbodies reported by the KDF. Therefore, subsistence catches were assumed be additional to baseline catches. Subsistence catches from licensed fisher-households were estimated for nine waterbodies with number of licensed fisher anchor points available (Appendix Table A1-A7): Lake Victoria and all the waterbodies in the 'Lakes, dams and TRD,' excluding Turkwel Dam (Table 1). Annual estimates of fisher-household catch for each waterbody were estimated using time series of people in fisher-households and annual fish consumption rates for people in fisher households.

First, time series of licensed fishers were produced for all nine waterbodies. Number of licensed fishers were linearly interpolated between available anchor points. A full time series of number of licensed fishers was produced for Lake Victoria via this method, the remaining eight waterbodies did not have number of licensed fishers available for, or prior to, 1950. Thus, number of licensed fishers for these waterbodies were estimated back to 1950 from the earliest available anchor point, assuming that the number of licensed fishers changed (i.e., decreased) with the rate of change in population density for the county/province in which each waterbody was located.

Secondly, the total number of people in fisher-households for each waterbody and year was estimated by multiplying the annual average household size by the number of licensed fishers for each year. A time series of average household sizes (in numbers of people) was derived for each county/province in which the nine waterbodies were located by linearly interpolating between single year average household sizes reported in historical Kenyan censuses (KNBS 1957, 1967, 1974, 1982, 1994, 2002, 2012, 2019).

Thirdly, a time series of annual fish consumption rates for people in fisher households was produced. Annual *per capita* fish consumption rates for people in fisher-households differed depending on the waterbody. For Lake Victoria, a rate of 90 kg/year for people in fisher-households surrounding Lake Victoria in 1995 was taken from Bokea and Ikiara (2000). For Lake Turkana, a rate of 73 kg/year for people in fisher-households surrounding Lake Turkana in 1982 was taken from Kolding (1989). These were the only two annual fish consumption rates for people in fisher-households identified in the literature and so to remain conservative, the rate of 73 kg/year was used for the remaining seven waterbodies.

In the decades leading up to, and during the 1980s and 1990s, there was an increase in the availability of alternative food sources and the development of a cash-based economy in Kenyan fishing communities (Geheb 1997a, Ochieng and Maxon (eds) 1992), in addition to major increases in fish prices (Abila 2003). These factors likely incentivised fishers to sell a larger portion of their catches and therefore consume less catch. Thus, *per capita* fish consumption rates in fisher households likely decreased in the decades preceding the 1980s. To account for this likely decrease in fish consumption, due to the lack of information for earlier periods and based on the method used in Vianna et al. (2020), fish consumption rates for people in fisher-households from Lake Victoria were assumed to be 20% higher in 1950 than in 1995 (i.e. 108 kg). To remain conservative, it was assumed that this rate would continue to decline at the rate of 0.4 kg/year after 1995, thus, a consumption rate of 81.2 kg/year was determined for 2017. For the remaining eight waterbodies, fish consumption rates were assumed to have declined at the same rate as those for Lake Victoria from 1950-2017, and therefore were assumed to be 14% higher in 1950 than in 1982 (i.e. 83.5 kg/year) and 62.5 kg/year for 2017. Consumption rates were then linearly interpolated from 1950-1995, and 1995-2017 for Lake Victoria, and 1950-1982, and 1982-2017 to produce a time series of fish consumption rates for people in fisher households.

Finally, total catches from-fisher households were calculated for each waterbody by multiplying the number of people in fisher households by the annual fish consumption rates for people in fisher households for each year from 1950-2017. These catches were then added to the reported catches for Lake Victoria and all waterbodies in the 'Lakes, dams and TRD' category, excluding Turkwel Dam. Catches from fisher-households were assumed to have the same taxonomic composition as reported catches. Fishing without licenses is a common practice in freshwater bodies throughout Kenya (e.g., Etiegni et. al. 2017), therefore fisher-household catches estimated from this study, based on number of licensed fishers, are likely minimum estimates.

2.4.2. Illegal catch from Lake Victoria

Illegal fishing, including the use of illegal fishing gears, taking undersize fish and fishing in prohibited areas, has occurred throughout Kenya's portion of Lake Victoria throughout the period of 1950-2017 (Lake Victoria Fisheries Service 1959, Cowx et al. 2003, Etiegni et al. 2017). Catches from illegal fishing are largely unreported (Coche and Balarin 1982, Cowx et al. 2003). Coche and Balarin (1982) estimated that an additional 25% of reported catches from Lake Victoria were unreported as a result of illegal fishing in 1982. Higher estimates of unreported catches from Lake Victoria were also outlined in Coche and Balarin (1982) but to remain conservative, the lowest estimate of 25% was used in this study. This additional 25% was added to all baseline catches from Lake Victoria for the period 1950-1982, and all catches, excluding Nile perch, from 1983-2017. It was assumed that the taxonomic composition of illegal catches was the same as those from reported catches for Lake Victoria. No evidence was found to suggest that the proportion of illegal catches decreased before or after 1982, therefore the 25% figure was used across the entire period of 1950-2017.

Cowx et al. (2003) estimated that an additional 20% of reported Nile perch catches from Lake Victoria were unreported as a result of illegal fishing activites in 2003. Consultation with experts on Kenya's freshwater fisheries indicated that this figure had increased to an additional 30% of reported Nile perch catches by 2017 (Paul Tuda, Leibniz Centre for Tropical Marine Research, pers comm., Ian Cowx, Hull International Fisheries Institute, pers comm.). The only other estimate of illegal, unreported catches from Lake Victoria prior to 2003 was the 25% from Coche and Balarin (1982), therefore, it was assumed that the percentage of illegal, unreported Nile perch catches was also 25% from 1950-1982. The percentage of illegal, unreported Nile perch catches from Lake Victoria was assumed to have decreased linearly from 25% in 1982 to 20% in 2003, and then increase linearly to 30% in 2017. Thus, an additional 25% of Nile perch was added to baseline Nile perch catches from

Lake Victoria from 1950-1982, and then an additional 20-30%, depending on the year, was added from 1983-2017. There may be sources of unreported catches from illegal activities from other freshwater bodies in Kenya, but no such estimates were identified in this study.

2.4.3. Bait catch from Lake Victoria

A major longline Nile perch fishery has existed in Lake Victoria since the mid-1990s. Bait caught for use in this fishery is believed to be unreported (Cowx et al. 2003, Mkumbo and Mlaponi 2007). Both Kenya and Tanzania have similar Nile perch longline fisheries (Paul Tuda, Leibniz Centre for Tropical Marine Research, pers comm., Kevin Obiero, Kenya Marine and Fisheries Institute, pers comm). Therefore, estimates and taxonomic compositions of unreported bait catches for use in the longline Nile perch fishery in Tanzania's portion of Lake Victoria from Mkumbo and Mlaponi (2007) were used as a proxy to calculate unreported bait catches in Kenya as no estimates of unreported bait catches exist for Kenya. It was assumed that the unreported bait for this fishery would increase proportionally to the number of longline hooks. Thus, the number of longline hooks reported for Kenya's portion of Lake Victoria (LVFO 2016) was used to estimate unreported catch. Due to a lack of information, it was assumed that the longline Nile perch fishery began in 1981 as this was when reported Nile perch catches first rapidly increased (Greboval and Fryd 1993). Thus, estimated bait catches for this fishery were added to total reported catches for Lake Victoria from 1981-2017.

2.5. Separating catches by fishing sector

All catches, reported and unreported, were allocated to sectors: artisanal and subsistence as these were the only two identified in the literature. All reported catches from Lake Victoria, waterbodies in the 'Lakes, dams and TRD' category and unreported bait catches were allocated 100% to the artisanal sector. All catches from licensed fisher-households were allocated 100% to the subsistence sector. Due to a lack of evidence, catches from waterbodies in the 'Rivers' category and illegal, unreported catches were assumed to be 50% subsistence and 50% artisanal.

2.6. Quantifying data reliability

The reliability of the data and data sources (i.e. uncertainty) of the complete reconstructed catch time series was quantified using a scoring method described in Zeller et al. (2016) and previously applied to marine catches (Pauly and Zeller 2016a, 2016b) (Table 2). This method was adapted from the Intergovernmental Panel on Climate Change when using multiple and differing sources of evidence (Mastrandrea et al. 2010). Data reliability scores and percentage uncertainty bounds were determined based on my evaluation of the reliability of the secondary data and information sources used to reconstruct catches for each of the three categories: 'Lake Victoria'; 'Lakes, major rivers and dams'; 'Rivers.' Data reliability scores and percentage uncertainty bounds were calculated for four time-periods (1950-1969; 1970-1989; 1990-2009; 2010-2017) for each waterbody category and fishing sector. Total data reliability scores and percentage uncertainty bounds were derived for each time period based on the catch-weighted averages from each category and fishing sector.

Table 2. Scoring system to derive reliability for reconstructed catch time series data. IPCC criteria from Figure 1 in Mastandrea et al. (2010) and adapted by Pauly and Zeller (2016a).

Score	Description	± %	Corresponding IPCC criteria
4	Very high	10	High agreement and robust evidence
3	High	20	High agreement and medium evidence or medium agreement and robust evidence
2	Low	30	High agreement and limited evidence or medium agreement and medium evidence or low agreement and robust evidence
1	Very low	50	Less than high agreement and less than robust evidence

3. Results

3.1. Reported baseline

The available freshwater catch data reported by the KDF from 1967-2017 matched closely with data reported by the FAO on behalf of Kenya up to 2008 **(**Figure 2**)**. Between 2008 and 2016, catches reported by the FAO were on average 21,000 t/year (12%) higher than those reported by the KDF. FAO reported catches increase to a post-2000 maximum of approximately 170,000 t in 2011, after which they decline to approximately 100,000 t in 2017, while KDF reported catches reach a post-2000 maximum of approximately 150,000 t in 2006 and then follow an overall declining trend thereafter.

The catches reported by the FAO on behalf of Kenya were comprised by a maximum of 15 taxonomic groups, of which only three were reported prior to 1975. In contrast, catches reported by the KFD were comprised of 22 different taxonomic groups, of which 14 were reported prior to 1975 (Table 3).

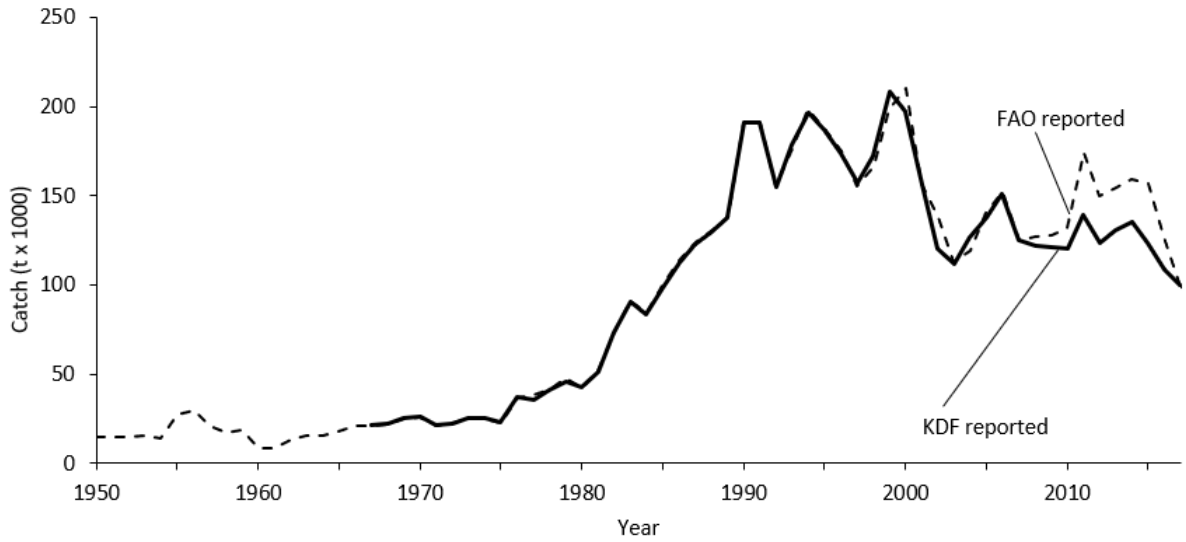

Figure 2. Total freshwater catches reported by the FAO on behalf of Kenya from 1950-2017 and nationally reported by the KDF from 1967-2017.

Table 3. Catch taxonomic categories reported by the KDF and FAO from 1950-2017. Categories reported prior to 1975 are shaded.

KDF	FAO
-	Arican lungfishes
Alestes spp.	-
Anguilla spp.	-
Barbus spp.	-
Bagrus spp.	-
Clarias spp.	-
Citharinus spp.	-
Coptodon zilii	-
Cyprinus carpio	*Cyprinus carpio*
Distichodus spp.	-
-	Cyprinids nei*
Freshwater fishes nei*	Freshwater fishes nei*
Haplochromis spp.	-
Hydrocynus forskahlii	-
Labeo spp.	-
-	Mouthbrooding cichlids
Mormyrus spp.	-
Nile perch (*Lates niloctilus*)	Nile perch (*Lates niloctilus*)
Nile tilapia (*Oreochromis niloctilus*)	Nile tilapia (*Oreochromis niloctilus*)
-	Naked catfishes
Procambarus clarkii	-
Protopterus spp.	-
-	Red swamp crawish
-	Rhinofishes nei*
-	*Salmonids* nei*
Schlibe spp.	-
Silver cyprinid (*Rastrineobola argentea*)	Silver cyprinid (*Rastrineobola argentea*)
Synodontis spp.	-
Tilapias nei*	Tilapias nei*
-	Torpedo-shaped catfishes nei*
-	Upside-down catfishes

*Not elsewhere included

3.2. Total reconstructed catches

Total reconstructed catches from 1950-2017 were 7.8 million t and approximately 32% (1.9 million tonnes) higher than the data reported by the FAO on behalf of Kenya (Figure 3, Appendix Table A12**)**. Reconstructed catches remained relatively stable at approximately 30,000 t/year in the 1950s, after which they declined to a low of 13,000 t in 1962. From 1963 to the mid-1970s, reconstructed catches steadily increased to around 40,000 t/year, after which they strongly increased in the 1980s to a time series peak of 270,000 t in 1999. After 2000, they declined by 46% over the next 18 years to 145,000 t in 2017 (Figure 3). Trends in total reconstructed catches are similar to those in data reported by the FAO on behalf of

Kenya from 1950- 1999. From 2000-2017, the trend in reconstructed catches more closely aligns with catch trends in KDF reported data, also reaching a post-2000 maximum in 2006, followed by an overall declining trend thereafter.

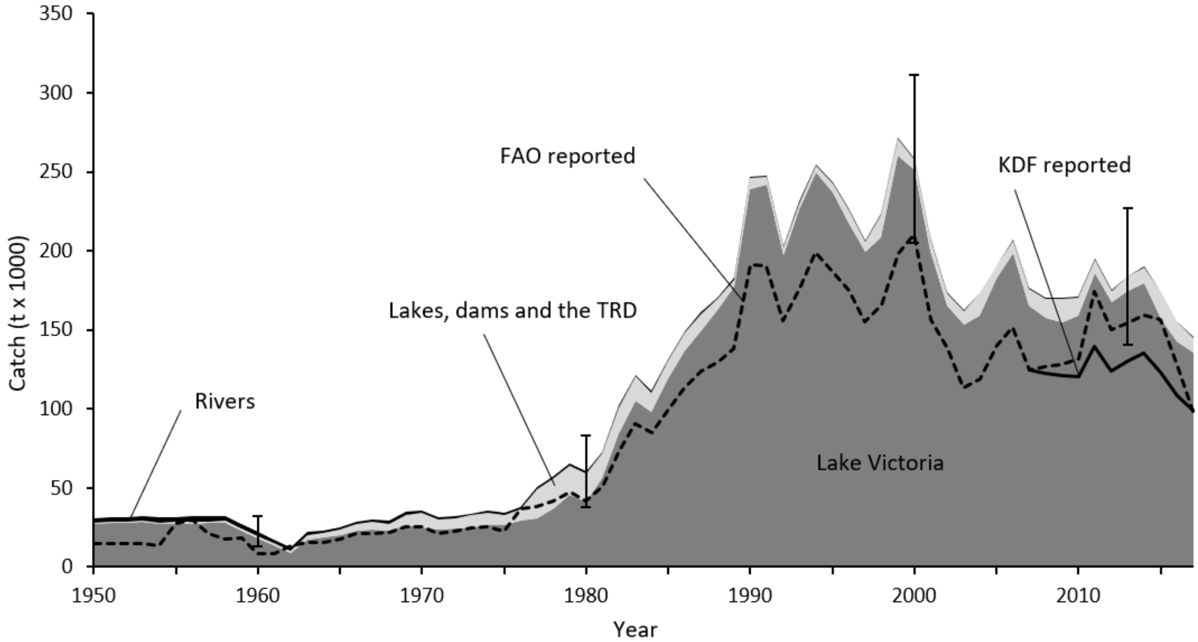

Figure 3. Total reconstructed freshwater catches for Kenya from 1950-2017, separated by waterbody category. Data reliability bounds are included as catch-weighted averages for the 1950-1969, 1970-1989, 1990-2009 and 2010-2017 periods. Freshwater catches as reported by the FAO on behalf of Kenya are overlaid as a dashed line, and KDF reported catches for 2008-2017 are overlaid as a solid line.

The artisanal fishing sector accounted for around 80% of total reconstructed catches, while the subsistence sector accounted for 20% (Figure 4a, Appendix Table A12). The majority of artisanal catches (91%) were reported (Figure 4b), while 95% of subsistence catches were unreported. Of the 1.9 million tonnes of unreported catch, approximately 71%, or 1.3 million tonnes were from the subsistence sector (Figure 4b).

Lake Victoria accounted for 92% of total reconstructed catches, with the ‘Lakes, dams and TRD’ category accounting for 7% and the ‘Rivers’ category comprising the remaining 1% (Figure 3, Appendix Table A12**)**.

The data and information reliability scores were lowest for 1950-1969 (1.7, Appendix Table A13), driven by a lack of data and supplementary information for all waterbodies resulting in the highest percentage uncertainty bounds around catches of ± 34% (Figure 4a). The latest two time periods (1990-2009, 2010-2017) had the highest data and information reliability scores (2.7, Appendix Table A12), resulting in the lowest percentage uncertainty bounds around total catches of ± 25% (Figure 4a) as a result of the high-quality data, information and publications by the KDF for Lake Victoria and waterbodies in the 'Lakes, dams and TRD category.' Subsistence catches were associated with the lowest data reliability scores (1, Appendix Table A12) as a result of the assumptions that calculations of catches from this sector were based upon. Artisanal catches had relatively high data reliability scores

In total, 22 taxonomic groups were included in total reconstructed catches from, of which Nile perch (35%), silver cyprinid (27%) and species from the genus *Oreochromis* (14%), accounted for the majority of catches (Figure 5).

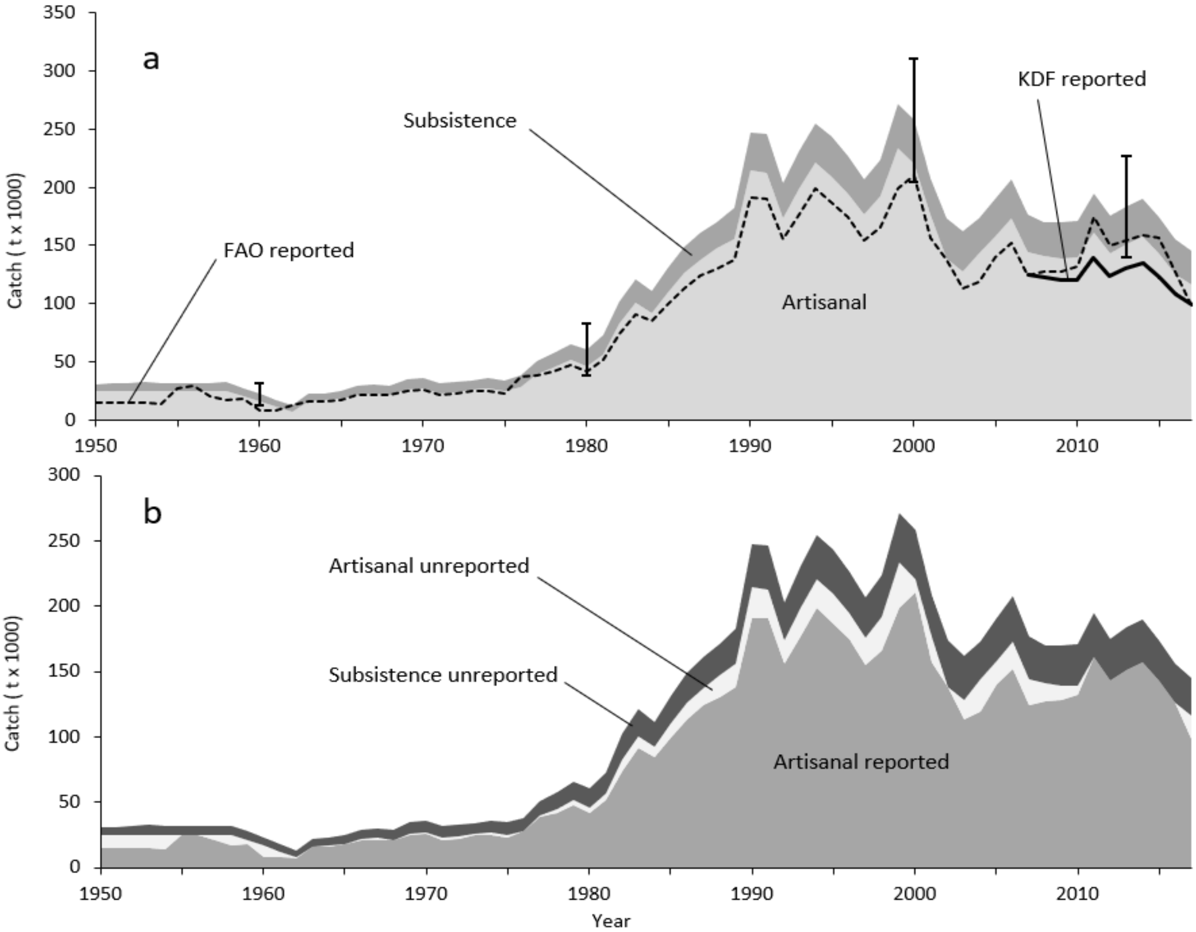

Figure 4. Total reconstructed freshwater catches for Kenya from 1950-2017 by a) fishing sector with data reliability bounds included as catch weighted averages for the 1950-1969, 1970-1989, 1990-2009 and 2010-2017 period; and b) by fishing sector and reporting status within each fishing sector. Reported subsistence catches accounted for approximately 4% of total subsistence catches but were too small to be visible in the graph.

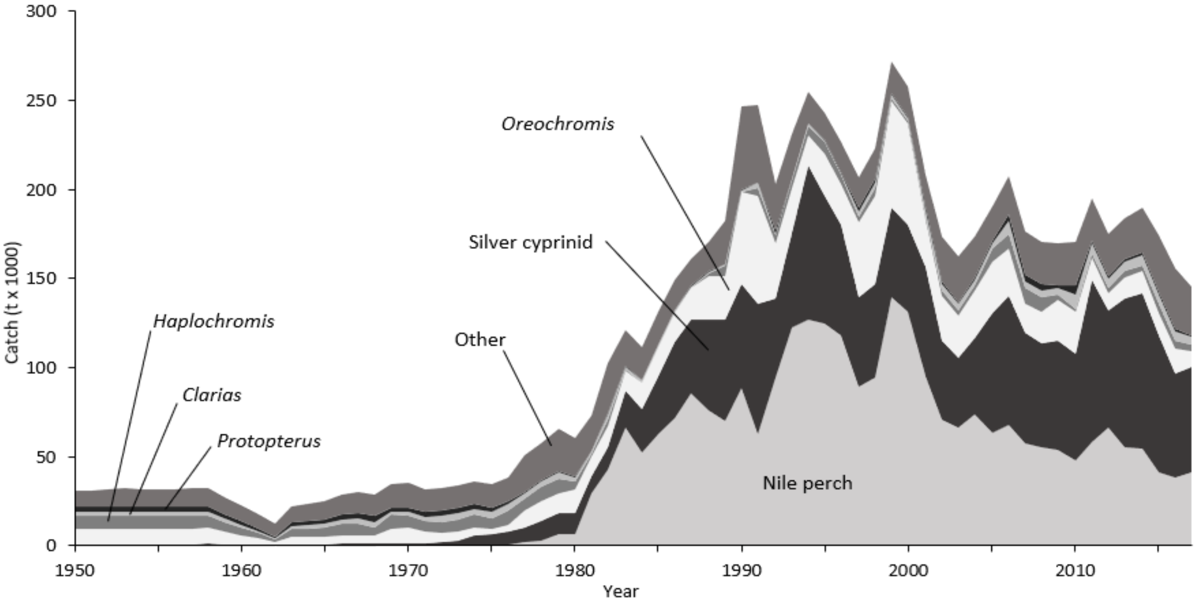

Figure 5. Total reconstructed catches from 1950-2017 by taxa, with the 'Other' category including 15 additional taxa.

3.3. Lake Victoria

Reconstructed catches for Lake Victoria remained stable at approximately 27,000 t/year in the 1950s, then declined to a low of 8,600 tonnes in 1962, before steadily increasing thereafter, at an average rate of 1,400 t/year, reaching 42,000 t in 1980 (Figure 6a, Appendix Table A12**)**. In the 1980s, catches increased by 20,000 t/year, reaching 239,000 t in 1990. Catches peaked at 260,000 t in 1999 and thereafter declined by 48% over the following 18 years to 135,000 t in 2017.

Nile perch (38%), silver cyprinid (29%) and species from genus *Oreochromis* (13%) accounted for the majority of total catches (Figure 6a). The taxonomic composition of catches prior to 1980 were relatively diverse, with species from the genera *Oreochromis* (21%), *Haplochromis* (19%), *Clarias* (8%) and *Protopterus* (7%) accounting for the majority of catches. After 1980, reconstructed catches were dominated by three taxa: Nile perch (40%), silver cyprinid (30%) and species from the genus *Oreochromis* (13%).

Artisanal fishing dominated catches from Lake Victoria, accounting for 80% of total catches (Figure 6b, Appendix Table A12**)**. Subsistence catches declined from 24% of total catches prior to 1980 to 18% in the 2010s.

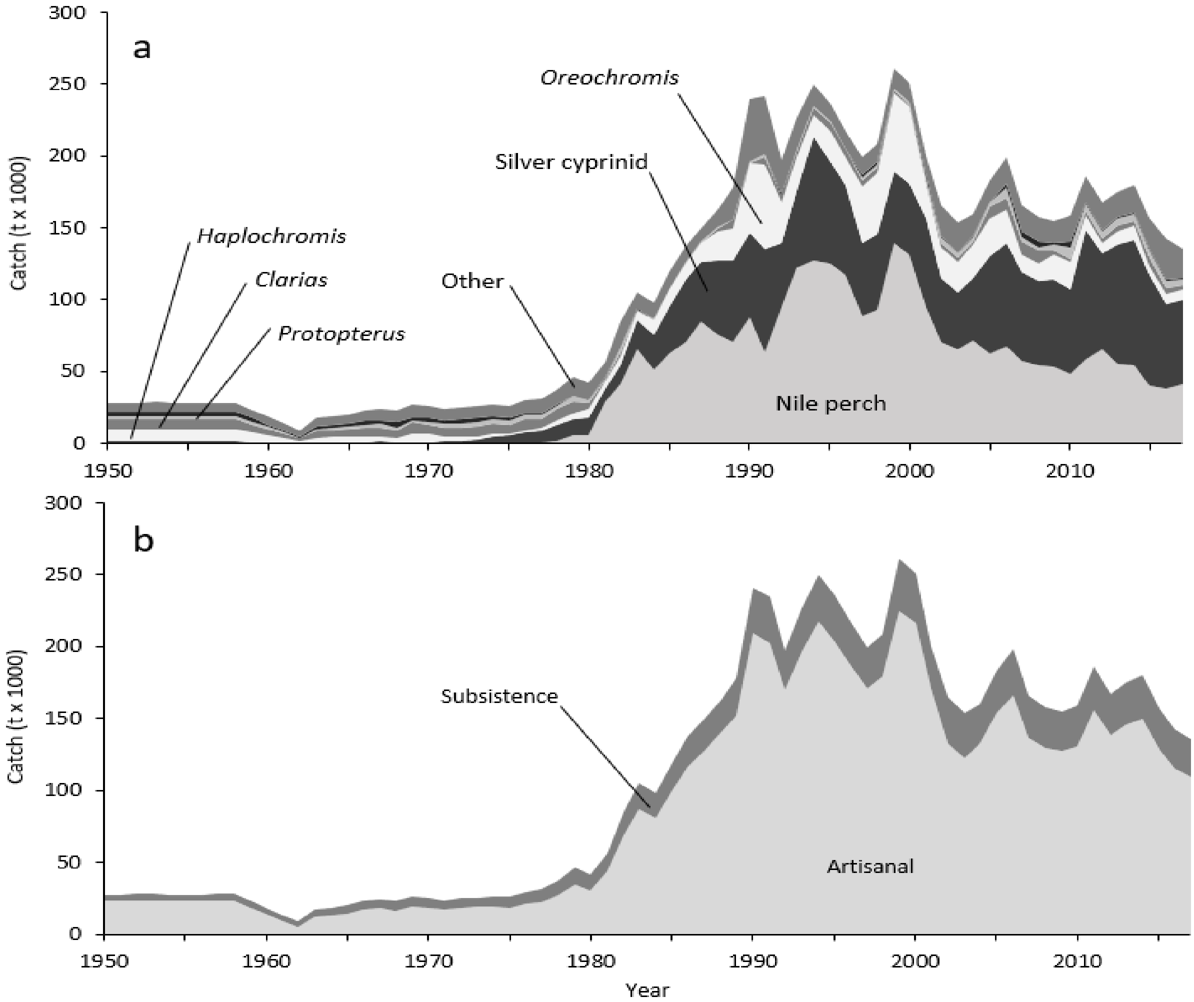

Figure 6. Total reconstructed catches for Lake Victoria from 1950-2017 by a) the six major taxa, plus an ‘Other’ category that includes an additional eight taxa; b) fishing sector.

3.4. Lakes, dams and TRD

Trends in reconstructed catches from the 'Lakes, dams and TRD' category were mainly driven by trends in catches from Lake Turkana, which accounted for 72% of catches in this waterbody category (Figure 7a, Appendix Table A12). Catches from this category increased from approximately 1,000 t/year in the 1950s to around 5,000 t/year in the early 1970s. Catches increased massively to a peak of 19,000 tonnes in 1977, exclusively driven by high water levels in Lake Turkana (Gownaris et al. 2017) greatly increasing breeding grounds for Oreochromines, and facilitated by a Norwegian fisheries development program (Kolding 1989). Catches declined to approximately 5,000 t/year in the early 1990s, thereafter fluctuating greatly between 3,000 t/year and 12,000 t/year.

Catches from the 'Lakes, dams and TRD category' were also dominated by artisanal fishing, which accounted for 80% of total catches, with the subsistence accounting for the rest (Figure 7b, Appendix Table A12**)**. The taxonomic breakdown of total reconstructed catch from this category was relatively diverse, with species from the genera *Oreochromis* (39%), *Labeo* (12%), *Clarias* (5%), as well as Nile perch (7%) accounting for the largest portions of catch among a total of 20 taxonomic groups (Figure 7c).

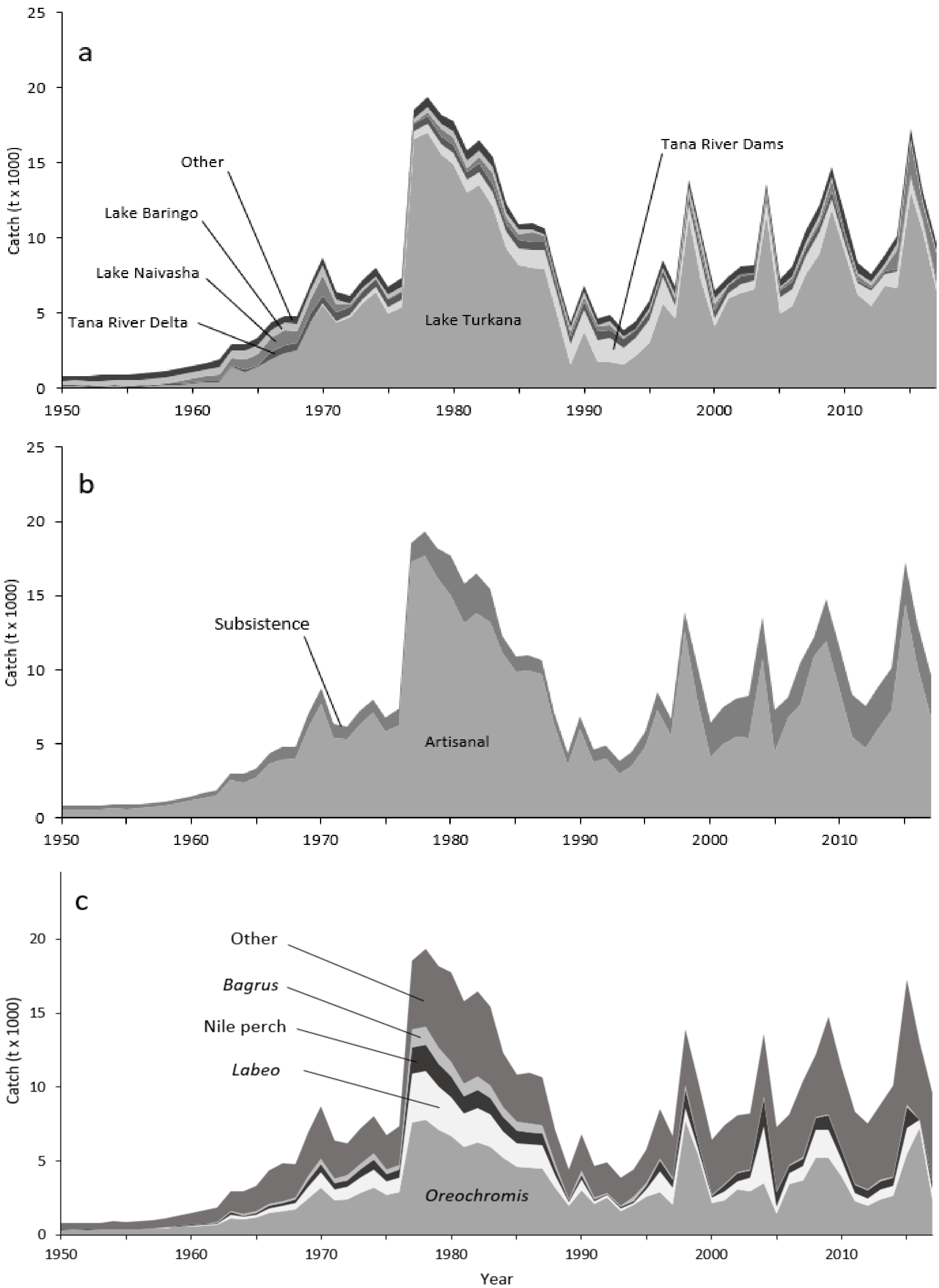

Figure 7. Total reconstructed catches for the 'Lakes, dams and TRD' category by a) waterbody, with the 'Other' group containing 4 additional waterbodies, b) fishing sector, and c) the four major taxa, plus an additional 17 additional taxonomic groups in the 'Other' category.

3.5. Rivers

Reconstructed catches from the 'Rivers' category peaked in the mid-1950s at 3,400 t/year, driven by peaks in catch from the Sondu-Miriu, Nzoia and Kuja rivers. Catches then declined throughout the remainder of the time series to just over 200 t in 2017 (Figure 8, Appendix Table A12**)**. The percentage contribution of catch from each river remained relatively constant from 1950-2017. Total percentage contributions were: Nzoia river (27%); Kuja river (26%); Sondu-Miriu river (18%); Athi-Sabaki river (14%); Ewaso-Ngiro river and swamp (14%); Malewa river (1%). Due to limited data available for waterbodies in this category after 1964, the trends in catch after the mid-1960s are primarily a result of the conservative assumptions made in this study and therefore are likely underestimates.

Taxonomic compositions of catches from waterbodies in the 'Rivers' were not available in the literature, therefore all catches were categorised as 'Freshwater fishes not elsewhere included.'

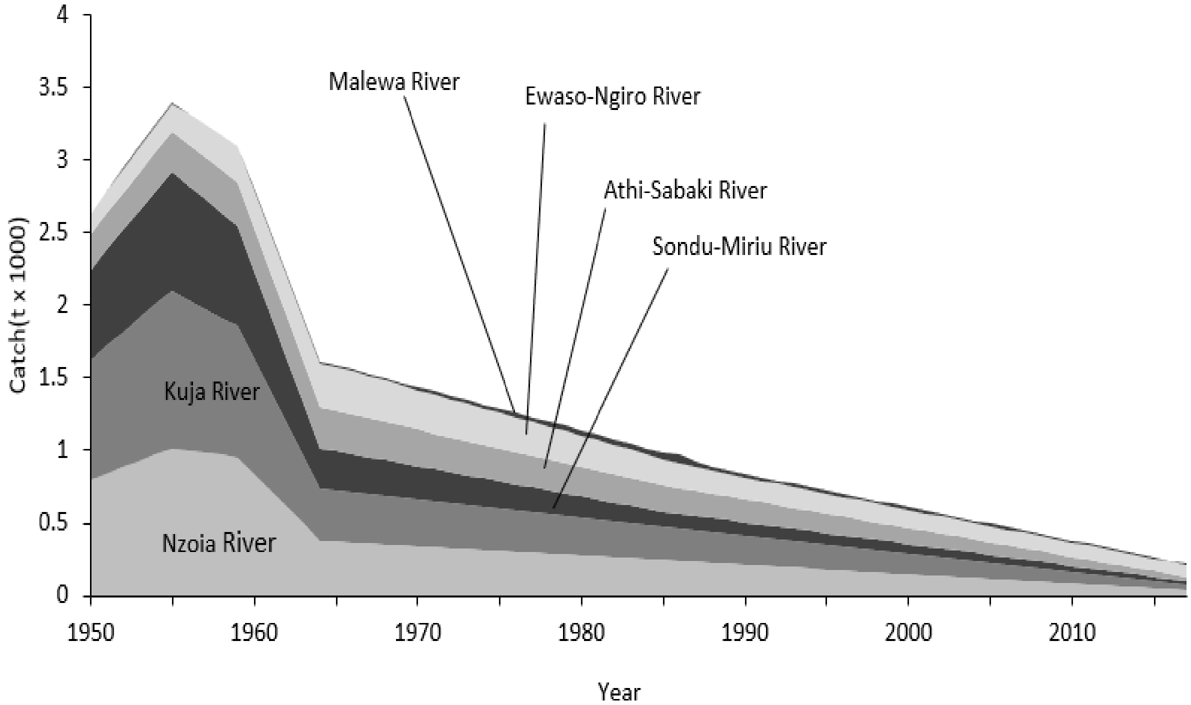

Figure 8. Total reconstructed catches for the 'Rivers' category by waterbody.

4. Discussion

Total reconstructed catches were 32% higher than data reported by the FAO on behalf of Kenya from 1950-2017. This discrepancy was primarily driven by under-reporting of locally consumed catches from the subsistence sector, which accounted for 71% of unreported catches. This indicates that freshwater catches for local consumption are greatly under-represented in nationally reported statistics and are likely undervalued by management authorities in Kenya. As these fish provide an important source of nutrition for people in Kenya, it is crucial that catch for local consumption receives greater management attention. Catches from Lake Victoria dominated reconstructed catches, with changes in the taxonomy of catches from 1950-2017 closely matching those described in the literature for Kenya's Lake Victoria fishery (Ogutu-Ohwayo 1990, Cowx et al. 2003, Kolding et al. 2014). Silver cyprinid and Nile perch catches accounted for 70% of reconstructed catches from Lake Victoria after 1980. Catches of these two species have largely been exported or converted to animal feed since 1980, and are represented fairly accurately in reported data. (Cowx et al. 2003, Paul Tuda, Leibniz Centre for Tropical Marine Research, pers. comm.). This under-representation of catches for local consumption in national statistics, while catches for non-local human uses are well represented, also reflects patterns in global freshwater and marine fisheries datasets, where more lucrative fisheries focused on catch for non-local food consumption tend to receive the bulk of management attention, while fisheries for local food consumption tend to receive limited attention (Welcomme 2011, Pauly and Zeller 2016a).

The results of this study provide a more complete picture of Kenya's capture fisheries from 1950-2017 when considered alongside the reconstructions of Kenya's marine fisheries by Le Manach et al. (2016) and (McAlpine 2019). Total unreported catches in Kenya from 1950-2017 amount to 3 million t, with 1.1 million t from marine and 1.9 million t from freshwater fisheries. Unreported marine catches, as a proportion of FAO reported catches, were much higher (160%) than unreported freshwater catches (32%). This does not align with differences between previous re-estimates of global freshwater (The World Bank 2012, Lymer et al. 2016, Fluet-Chouinard et al. 2018) and global marine catches (Pauly and Zeller 2016a, 2016b), where the proportion of unreported catches, relative to FAO reported catches, are much higher from freshwater catch estimates.

These difference in global re-estimates of freshwater and marine catches could in part be explained by the conservative approach used by Pauly and Zeller (2016a, 2016b). Kenya's total national marine and freshwater reconstructed catches, however, are dominated by catches from the export-oriented freshwater fishery of Lake Victoria, which accounted for 83% of total reconstructed catches from 1950-2017. Therefore, the bulk of historical fisheries management attention and resources in Kenya are likely to have been allocated to Lake Victoria's fishery, at the expense of Kenya's marine fisheries. The lack of management focus on marine fisheries may have resulted in traditional data collection system not accounting for a larger portion of catch compared to freshwater fisheries. For many coastal countries, reported marine catches far exceed reported freshwater catches (FAO 2020a). Therefore, Kenya may be an outlier in the proportion of unreported marine catches exceeding the proportion of unreported freshwater catches. To further investigate this, future freshwater catch reconstructions could focus on coastal countries where reported marine catches far exceed reported freshwater catches to determine whether the case of Kenya is indeed distinct.

4.1. Misreporting of aquaculture production

Freshwater catches reported by the FAO on behalf of Kenya from 2008-2016 followed a different trend to, and were an average of 21,000 t/year higher than total reconstructed and KDF reported catches. This period coincided with an expansion in reported aquaculture production in Kenya. Aquaculture production increased from 4,500 t in 2008 to a peak of 24,000 t in 2014 and then decreased to 15,000 t in 2016 (KDF 2008, 2016). These values closely match the differences in catch reported by the FAO and KDF over this period. After consultations with Kenyan fisheries experts and James Geehan, the FAO Fisheries Statistician in charge of FAO's Global Capture Production database, it seems likely that the wild capture data reported by the FAO on behalf of Kenya during 2008-2016 mistakenly included aquaculture production, as has been observed historically in freshwater fisheries globally (Welcomme 2011; Bartley et al. 2015). This is concerning as the misrepresentation of trends in catch and inflation of catch totals that this misreporting may have caused in FAO reported data could compromise the policy and management-related decisions on national and global scales that often rely on FAO reported data. This suggests that the Kenyan government should request and resubmit a retro-active data correction of their FAO data (Garibaldi 2012) to ensure that total catches and trends from 2008-2016 are not mis-represented in FAO reported data. Additionally, this indicates that there may be a larger proportion of unreported catches, from 2008-2016, than the 21% identified in this study.

4.2. Meeting the policy target of increased domestic fish consumption

Increasing per capita fish consumption to 10kg/year by 2030, more than double that of current levels of 4.7kg/year, is a central goal of the Kenya Vision 2030 long-term development blueprint (KMFRI 2018). Reconstructed catches indicate that current consumption levels may be higher than reported data would suggest, given that most of the unreported catches are likely consumed locally. However, for average per capita consumption rates to reach 10 kg/year, total catch from freshwaters would have to increase from the reconstructed total of 145,000 tonnes in 2017 to approximately 550,000 tonnes by 2030. This figure takes into account projected population growth (Obiero et al. 2019) and assumes that current marine reconstructed catches (McAlpine 2019), aquaculture production, fish imports and exports remain at 2017 levels (KDF 2017).

It is unlikely Lake Victoria can support an increase in catches to accommodate a 10 kg *per capita* fish consumption rate given the 48% decline in unreported and reported catches since 1999, despite effort remaining relatively stable (LVFO 2016), and reported declines in fish stocks since 2014 (Aura et al. 2020). This shortfall is unlikely to be met by Lake Turkana's currently under-developed fishery as it has an estimated maximum sustainable yield of only 30,000 t/year (KMFRI 2018). Increasing the amount of affordable domestically caught freshwater fish that are available for local consumption is important, but alternative sources of fish are also required to support this increase in fish consumption.

Increasing fish imports could be a way of increasing consumption. However, the negative impacts of recent increases in Chinese tilapia imports on Kenyan fisher's incomes and livelihoods (Dijkstra 2019) demonstrates that any increases in imports need to be carefully considered to ensure that local negative impacts are minimised. Aquaculture production has increased in recent years and has the potential to be a major future supplier of domestic fish as well as supporting Kenyan livelihoods (Obiero et al. 2019). However, increasing current production levels from 12,000 t/year (KDF 2017) to a figure large enough to support a *per capita* fish consumption rate of 10 kg/person in 10 years would require massive growth (Obiero et al. 2019) and would likely be reliant on fishmeal which is associated with a range food insecurity issues, both in Kenya and globally (Abila 2003, Cashion et al. 2017) .

Kenya's offshore marine domestic fishery has potential for major future growth, with essentially only foreign fishing occurring in this region (McAlpine 2019). Expanding this fishery could provide a major new source of fish for domestic consumption. Tuna form the majority of current foreign offshore catches in Kenya's EEZ and these are often exported to high priced international markets rather than being consumed domestically. Therefore, it is important that catch for local consumption is seen as a priority by management authorities and political leaders when looking at expanding marine fisheries.

4.3. Future data improvements

This study has produced a conservative estimate of Kenya's freshwater catches that has improved upon the accuracy of existing reported datasets. As with any catch estimates, a level of uncertainty does exist with the data produced in this study as a result of the assumptions made. Assumptions were made to estimate catches for periods without anchor points, most notably for waterbodies in the 'Rivers' category due to the limited data available. However, all attempts were made to remain conservative in making these assumptions and estimates of catch from the anchor points used for waterbodies from this category were in many cases only for small portions of each waterbody (Appendix Table A9). Therefore, estimates of catch based on these assumptions are likely minimum estimates. These assumptions were accounted for by assigning the lowest data reliability scores to all catches from the 'Rivers' category. Given that catches from waterbodies in the 'Riverine' category only accounted for 1% of total reconstructed catches, the assumptions made in estimating catches from this category did not majorly affect overall catch trends or totals. Future research should focus on identifying catch estimates from waterbodies in the 'Rivers' category in more recent years to improve the accuracy of the catch time series from this study.

Two assumptions were made for subsistence catches due to limited information being available describing the methods used by the KDF to estimate total catches for any freshwater bodies. These were: i) subsistence catches from licensed fisher-households and illegal fishing from Lake Victoria were completely separate; ii) catches from licensed fisher-households and catches from illegal fishing were unreported. Some licensed fishers may fish illegally to provide catch for consumption in their households, thus creating some potential cross-over between subsistence catches from licensed fisher-households and illegal fishing presented in this study. A portion of catches from licensed fisher-households could be included in reported data and this portion could also vary between waterbodies and time periods. To address the uncertainties associated with these assumptions, future research should focus on obtaining and comprehensively evaluating the KDF catch estimation methods.

There were sources of freshwater catches in Kenya that were not covered in this study due to a lack of available information in nationally reported data and the secondary literature. Catch estimates were not produced for the 400km stretch of the Tana River between the Tana River Dams and the Tana River Delta, or the 150 km stretch of the Turkwel River that does not include the Turkwel Dam. Given that several towns/villages are located along these portions of the Tana and Turkwel rivers, fisheries likely exist. Additionally, Kenya's size, the number of freshwater bodies present throughout the country, the limited resources available for fisheries management and research, and the remote nature of many waterbodies means that it is likely that other waterbodies with fisheries exist that were not identified in this study. No information was available for catches from cross-border fishing that is known to occur on lakes Victoria and Turkana (Cowx et al. 2003, KDF 2016). Additionally, recreational fishing is known to occur in Lake Victoria (Coche and Balarin 1982), the Kenyan highlands, Lake Naivasha and Lake Nakuru (KMFRI 2018), however no catch estimates for these were identified in the literature reviewed. The exclusion of these sources of unreported catch in this study further supports the conservative nature of the unreported catches identified, and calls for future targeted investigations into these.

5. Conclusion

Collectively, the 3 million t of unreported catches from marine and freshwater fisheries from 1950-2017 demonstrate the major under-valuation of capture fisheries in Kenya. Incorporating sources of unreported catch identified from both marine and freshwater catch reconstructions in estimates of national catch will enable Kenyan fisheries management to make better informed decisions on ecosystem and fisheries management. Accounting for sources of unreported catch will also more accurately represent the value of capture fisheries in Kenya for local food security and livelihoods, which will better inform government decisions in allocating resources to management. This study has generated a more accurate estimate of Kenya's freshwater catches from 1950-2017 that improves on existing data on three main fronts: spatial waterbody coverage, sectoral disaggregation and taxonomic resolution. These data will be made freely available at http://www.seaaroundus.org/ for global uses. As the first freshwater catch reconstruction, this study has provided a template from which future freshwater catch reconstructions can be built upon, and has contributed to a better understanding of the importance of freshwater fisheries for local food security in developing countries.

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7. Appendices

Appendix Table A1. Anchor points used for reconstructing catches from Lake Victoria (Kenya) from 1950-2017.

Item	Year/s	Description	Source
Catch and taxa	1948	Total catch for Lake Victoria	KDF in Ogutu-Ohwayo (1990)
	1958	Total catch and taxonomic composition for Lake Victoria, including illegal gear catches	KDF in Lake Victoria Fisheries Service (1959)
	1961	Total catch for Lake Victoria (Kenya)	KDF in Ogutu-Ohwayo (1990)
	1962	Total catch for Lake Victoria (Kenya)	KDF in Ogutu-Ohwayo (1990)
	1964-1966	Total catch for Lake Victoria (Kenya)	KDF in Greboval and Fryd (1993)
	1967	Total catch for Lake Victoria (Kenya)	KDF in KNBS (1972)
	1968-1973	Total catch and taxonomic composition for Lake Victoria (Kenya)	KDF in Committee for Inland Fisheries of Africa (1988)
	1974-1985	Total catch and taxonomic composition for Lake Victoria (Kenya)	KDF in Reynolds and Greboval (1988)
	1986-1994	Total catch and taxonomic composition for Lake Victoria (Kenya)	KDF unpublished data, Christopher Aura, Kenya Marine and Fisheries Research Institute, pers. comm.
	1995-2017	Total catch and taxonomic composition for Lake Victoria (Kenya) 1994-2016, just total catch for 2017	KDF (1996, 1997, 2008, 2009, 2010, 2011, 2012, 2013, 2016, 2017, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007)
Unreported catch	1982	Unreported, illegal catches	Coche and Balarin (1982)
	2003	Unreported and illegally caught Nile perch:	Cowx et al. (2003)
	2007	Weight and taxonomic breakdown of unreported bait caught for use in the Nile perch longline fishery in Lake Victoria (Tanzania).	Mkumbo and Mlaponi (2007)
	2020	Unreported and illegally caught Nile perch	Ian Cowx, Hull Fisheries Institute, pers. comm., Paul Tuda, Leibniz Centre for Tropical Marine Research, pers. comm.
Number of fishers	1950-1954, 1956	Number of licensed fishers	Lake Victoria Fisheries Service in Geheb (1997b)

Appendix Table A1. Anchor points used for reconstructing catches from Lake Victoria (Kenya) from 1950-2017.

Item	Year/s	Description	Source
	1971, 1979, 1994, 1995	Number of licensed fishers	KDF in Bokea and Ikiara (2000)
	1973	Number of licensed fishers	FAO in Bokea and Ikiara (2000)
	1982-1991	Number of licensed fishers	KDF in Greboval and Fryd (1993)
	1996-2016	Number of licensed fishers	KDF (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016, 2017)
Fish consumption	1995	90kg per person per annum in fisher households	Bokea and Ikiara (2000)

Appendix Table A2. Anchor points used for reconstructing catches from Lake Turkana (Kenya) from 1950-2017.

Item	Year/s	Description	Source
Catch and taxa	1951-1956	Total catch and taxonomic composition	Kolding (1995)
	1962,1963, 1966	Total catch	KDF in Kolding (1989)
	1964	Total catch	KDF in FAO/UN (1966)
	1965	Total catch	FAO/UN in Welcomme (1979)
	1967-1991	Total catch	KDF in KNBS (1972, 1974, 1977, 1980, 1982, 1985, 1987, 1990, 1991, 1994)
	1992-1994	Total catch and taxonomic composition	KDF from Aura pers. comm. 2020
	1995-2017	Total catch and taxonomic composition (total catch only for 2014, 2015, 2017)	KDF (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016, 2017)
Number of fishers	1962-1988	Number of licensed fishers	Kolding (1989)
	1996-2013, 2016	Number of licensed fishers	KDF (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016)
Fish consumption	1982	73kg per person per annum in fisher households	NORAD in Kolding (1989)

Appendix Table A3. Anchor points used for reconstructing Lakes Baringo and Naivasha catches from 1950-2017.

Item	Year/s	Description	Source
Catch and taxa	1964	Total catch	KDF in FAO/UN (1966)
	1965	Total catch	FAO/UN in Welcomme (1979)
	1967-1991	Total catch	KDF in KBS (1972, 1974, 1977, 1980, 1982, 1985, 1987, 1988, 1990, 1991, 1992)
	1992-1994	Total catch and taxonomic breakdown	KDF unpublished data, Christopher Aura, Kenya Marine and Fisheries Research Institute, pers. comm.
	1995-2017	Total catch and taxonomic breakdown, (total catch only for 1995, 2014, 2015, 2017)	KDF (1996,1997,2000,2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016, 2017)
Number of fishers	1982, 1985, 1986	Number of licensed fishers	KDF in Vanden Bossche and Bernacsek (1990)
	1996-2013, 2016	Number of licensed fishers	KDF (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016)
Other	1959	Commercial fishery begins (Lake Naivasha)	Hickley et. al. (2002)
	1975	*Protopterus* introduced (Lake Baringo)	KMFRI (2018)
	1984	*Protopterus* first appears in commercial catch	KMFRI (2018)

Appendix Table A4. Anchor points used for reconstructing Lakes Kenyatta and Kanyaboli catches from 1950-2017.

Item	Year/s	Description	Source
Catch and taxa	2006	Total catch and taxonomic composition	KDF (2006)
	2007	Total catch taxonomic composition (Lake Kenyatta only)	KDF (2007)
	2008-2017	Total catch and taxonomic composition (catch only for 2013, 2015 and 2017)	KDF (2008, 2009, 2010, 2011, 2012, 2013, 2016, 2017)
Number of fishers	2004	Number of licensed fishers (Lake Kanyaboli only)	KDF (2004)
	2006-2013, 2016	Number of licensed fishers	KDF (2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016)

Appendix Table A5. Anchor points used for reconstructing Lake Jipe, Lake Chala and other fisheries in Taita-Taveta county catches from 1950-2017

Item	Year/s	Description	Source
Catch and taxa	1964- 1965	Total catch (Lake Jipe only)	KDF in FAO/UN (1966)
	1982	Total catch (Lake Jipe only)	KDF in Vanden Bossche and Bernacsek (1990)
	1983-1985	Total catch (Lakes Jipe and Chala only)	KDF in Vanden Bossche and Bernacsek (1990)
	1992-1994	Total catch and taxonomic composition	KDF unpublished data, Christopher Aura, Kenya Marine and Fisheries Research Institute, pers. comm.
	1995	Total catch	KDF (1996)
	1996-2017	Total catch and taxonomic composition (catch only for 2014, 2015, 2017)	KDF (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016, 2017)
Number of fishers	1965	Number of licensed fishers (Lake Chala only)	KDF in Vanden Bossche and Bernacsek (1990)
	1985-1986	Number of licensed fishers (Lakes Chala and Jipe only)	KDF in Vanden Bossche and Bernacsek (1990)
	1996-2013, 2016	Number of licensed fishers	KDF (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016)

Appendix Table A6. Anchor points used for reconstructing Tana River Dams catches from 1950-2017

Item	Year/s	Description	Source
Reported catch and taxa	1967	Potential annual catch from Kindaruma Dam	Mann (1969)
	1992-1994	Total catch and taxonomic breakdown	KDF unpublished data, Christopher Aura, Kenya Marine and Fisheries Research Institute, pers. comm.
	1995	Total catch	KDF (1996)
	1996-2017	Total catch and taxonomic breakdown (catch only for 2014, 2015, 2017)	KDF (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016, 2017)
Number of fishers	1996-2013, 2016	Number of licensed fishers	KDF (1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2016)
Other	1967	Construction of first major dam on Tana River (Kindaruma Dam) completed	Mann (1969)

Appendix Table A7. Anchor points used for reconstructing Tana River Delta catches from 1950-2017

Item	Year/s	Description	Source
Reported catch and taxa	1963	Total catch (lower stretches only)	Mann (1969)
	1964	Total catch (lower stretches only)	Mann (1969)
	1965	Total catch (lower stretches of river only)	Mann (1969)
	1966	Total catch (lower stretches of river only)	Mann (1969)
	2007-2009	Total catch	KDF (2007, 2008, 2009)
	2010-2017	Total catch and taxonomic breakdown (catch only for 2014, 2015, 2017)	KDF (2010, 2011, 2012, 2013, 2016, 2017)
Number of fishers	2016	Number of licensed fishers	KDF (2016)

Appendix Table A8. Anchor points used for reconstructing Turkwel Dam catches from 1950-2017

Item	Year/s	Description	Source
Reported catch and taxa	2013-2017	Total catch and taxonomic breakdown (catch only for 2014,2015, 2017)	KDF (2013, 2016, 2017)
Other	1990	Dam construction completed	Renshaw et al. (1998)

Appendix Table A9. Anchor points used for reconstructing catches for waterbodies assigned to the 'Rivers' category for 1950-2017

Item	Year/s	River	Description	Source
Reported catch and taxa	1955	Nyanzan* rivers	Total catch	FAO/UN (1966)
	1959	Sondu-Miriu river	Total catch	Whitehead (1959)
	1959	Kuja river	Total catch	Whitehead (1959)
	1959	Nzoia river	Total catch	Whitehead (1959)
	1960	Athi/Sabaki river	Total catch (lower portion of river)	Whitehead (1960)
	1964	Nyanzan* rivers	Total catch	FAO/UN (1966)
	1964	Ewaso- Ngiro river	Total catch	FAO/UN (1966)
	1965	Ewaso- Ngiro river	Total catch	FAO/UN (1966)
	1986	Malewa river	Total catch	KMFRI (2017)
	1986	Sondu-Miriu river	Total catch (lower reaches)	Ochumba and Manyala (1992)
	1987	Malewa river	Total catch	KDF (2017b)
	1987	Sondu-Miriu river	Total catch (lower reaches)	Ochumba and Manyala (1992)
	1990	Ewaso-Ngiro river	Total catch (swamp only)	KDF unpublished data, Christopher Aura, Kenya Marine and Fisheries Research Institute, pers. comm.
	2017	Sondu-Miriu river	Catch equivalent to subsistence levels in 2017	Julius Manyala, Jaramogi Oginga Odinga University of Science and Technology, pers. comm.
Number of fishers	1992	Sondu-Miriu river	Number of fishers	Ochumba and Manyala (1992)

*Includes the Kuja, Sondu-Miriu and Nzoia rivers

Appendix Table A10. Explanations of catch reconstruction methodologies where the general rules outlined in the Methodology section were not followed.

'Lakes, dams and TRD'
Catch for Turkwel Dam and Tana River Dams fisheries was assumed to be at 0 the year prior to the first dam being constructed on these rivers so as to account for the enhancement of fisheries that dam construction on rivers in Kenya is known to produce (Mann 1969). The years of dam completion were 1968 for the Tana River Dams (Mann 1969) and 1991 for Turkwel Dam (Renshaw et al. 1998). Catches were then linearly interpolated from 0 in 1967 (for the Tana River Dams) and 1990 (for Turkwel Dam) to earliest available catch anchor point (Appendix Tables A6, A8). As no information was identified for the state of the fisheries in these rivers prior to initial dam construction, catches were not estimated for these fisheries prior to these dates to remain conservative. Several other dams were constructed on the Tana River following the construction of the first dam in 1968 and although these may have influenced catches, no information was identified to quantify these changes. This should be a focus of future research. The commercial fishery of Lake Naivasha was known to begin in 1959 (Appendix Table A3), therefore baseline catches were assumed to be 0 in from 1950-1958. Catches were linearly interpolated from 0 in 1958 to the earliest catch anchor point to complete the catch time series. Thus, the only reconstructed catches for Lake Naivasha prior to 1959 were subsistence catches from licensed fisher-households.

Appendix Table A10. Explanations of catch reconstruction methodologies where the general rules outlined in the Methodology section were not followed.

'Rivers'
The only catch anchor point for the Athi/Sabaki river was for the lower portion of the river for 1959 (Appendix Table A9). Due to the lack of information and to remain conservative, it was assumed that catches from The Athi/Sabaki river peaked in 1959. The lower portion of this river is in the same province as the Tana River Delta (TRD). Thus, catches from the TRD were used as a proxy to estimate catches for the Athi/Sabaki River as no other information was available. The rate of decline of TRD catches from their peak in 1966 to 2017 was 1.5%/year. This value was used to produce a time series of catches for the Athi/Sabaki river from 1959-2017 based on the 1959 catch anchor point. Fisheries data for the Sondu-Miriu river was not available after 1987, however, catches were known to be equivalent to subsistence levels in 2017 (Appendix Table A9). Numbers of fishers were known for 1992 which were used to estimate the number of fishers in 2017 based on population density changes. Using the number of fishers, average number of people per household and the 73kg/year fish consumption rate for people in fisher-households from Kolding (1989), total subsistence catch for 2017 was estimated. Catches were then linearly interpolated from the 1987 catch anchor point to this 2017 value to complete the catch time series. Fisheries data for the Malewa, Kuja, Ewaso-Ngiro and Nzoia rivers were not available after 1990 (Appendix Table A9). The rate of decline of catches from the Sondu-Miriu river from the 1959 to 2017 was calculated (assuming conservatively that the 1959) which gave a rate of decline of ~ 1.5% per year. As the Malewa, Kuja and Ewaso-Ngiro rivers are in the same province as the Sondu-Miriu river and due to the lack of information, this rate of decline was used to estimate catch from the earliest anchor point from each river to 2017. All catch estimates produced for waterbodies in the 'Rivers' category using these methods resulted in declining catches from the earlier anchor points to 2017, therefore these are likely minimum estimates.

Appendix Table A11. Additional explanations of reconstructing catches and taxonomic compositions back to 1950 when no anchor points were available.

Reported catches and taxonomic compositions of catch fluctuated greatly from year to year for many waterbodies without following a distinct long-term trend of decline or increase. This was assumed to be the result of water level fluctuation in these waterbodies, which is often a major predictor of freshwater fisheries catch (Gownaris et al. 2017). No continuous water-level data spanning 1950-2017 were available for any waterbodies examined in this study. To account for this natural variability in water level, the closest consecutive five year mean of catch to population density ratio was used to estimate catches back to 1950 using changes in population density as a proxy. For example, if the earliest (i.e., closest to 1950) catch anchor points available for a waterbody were from 1965-69, the population density to catch ratio would be calculated for each of these five years and then the mean ratio for these five years would be derived. This five year mean ratio would be used to estimate catches from 1950-1964 based on the changes in population density in the province/county in which the particular waterbody is located. Several waterbodies did not have five consecutive years of catch anchor points available for this purpose, thus the two, three or four-year population density to catch ratio was used instead. To account for the intra-annual variability in taxonomic composition, the five-year mean of the taxonomic composition proportion for each species was calculated, where available, and then applied to all catches preceding it back to 1950.

Appendix Table A12. Total reconstructed catches (in tonnes) for Kenya's freshwater fisheries from 1950-2017, separated by waterbody category and sector.

	Lake Victoria		Lakes, dams and TRD		Rivers		Reconstructed total	FAO reported
Year	**Artisanal**	**Subsistence**	**Artisanal**	**Subsistence**	**Artisanal**	**Subsistence**		
1950	22875	4533	571	244	1319	1319	30860	15000
1951	22882	4734	594	251	1395	1395	31250	15000
1952	22889	4955	584	259	1471	1471	31628	15000
1953	22895	5519	593	267	1547	1547	32367	15200
1954	22902	4443	651	274	1623	1623	31515	13500
1955	22909	4559	628	281	1699	1699	31775	27400
1956	22916	4674	665	289	1662	1662	31867	29900
1957	22923	4869	741	296	1625	1625	32079	21000
1958	22930	5063	818	303	1588	1588	32290	17400
1959	18397	4751	995	311	1551	1551	27557	18300
1960	13865	4438	1183	317	1402	1402	22607	8300
1961	9333	4123	1365	325	1253	1253	17651	8400
1962	4801	3806	1548	332	1103	1103	12693	13200
1963	12459	4843	2577	399	953	953	22185	15600
1964	13500	5142	2433	544	806	806	23230	15800
1965	14625	5449	2718	608	794	794	24988	17600
1966	17100	5905	3696	679	778	778	28937	21300
1967	17717	6153	3978	864	763	763	30238	21300
1968	16561	6203	4063	745	748	748	29068	22100
1969	19583	6715	5993	960	733	733	34716	25200
1970	18671	6788	7716	1005	718	718	35616	25800
1971	16934	6768	5371	1020	703	703	31499	21300
1972	18115	6658	5334	849	688	688	32334	22300
1973	18901	6507	6234	939	673	673	33928	25000
1974	19322	7121	7136	881	659	659	35776	25165

Appendix Table A12. Total reconstructed catches (in tonnes) for Kenya's freshwater fisheries from 1950-2017, separated by waterbody category and sector.

	Lake Victoria		Lakes, dams and TRD		Rivers		Reconstructed total	FAO reported
Year	**Artisanal**	**Subsistence**	**Artisanal**	**Subsistence**	**Artisanal**	**Subsistence**		
1975	18654	7609	5851	934	644	644	34335	22810
1976	21015	8429	6272	1096	629	629	38070	36852
1977	21745	9063	17295	1267	614	614	50599	38403
1978	26804	10174	17722	1628	599	599	57527	41726
1979	34416	11563	16219	1985	584	584	65352	47628
1980	30278	11357	15038	2698	569	569	60509	42101
1981	42965	13015	13117	2690	554	554	72895	51305
1982	68621	16113	13790	2694	539	539	102295	73897
1983	86934	18055	13230	2188	523	523	121454	90956
1984	80802	17304	11134	1160	508	508	111416	84798
1985	99599	19913	9860	1017	493	493	131374	99647
1986	115859	21388	9993	994	487	487	149209	113465
1987	127305	22083	9682	979	459	459	160968	124180
1988	140398	22021	6354	792	446	446	170457	129819
1989	152031	25522	3596	815	433	433	182829	137989
1990	207844	31558	6000	842	419	419	247083	190993
1991	208541	32096	3796	869	408	408	246117	190305
1992	169391	27979	4008	897	396	396	203069	155644
1993	195818	30443	2970	926	385	385	230928	176435
1994	217066	32518	3478	956	374	374	254765	198805
1995	203981	32787	4816	986	362	362	243295	187241
1996	186852	30717	7331	1191	351	351	226793	174692
1997	170343	29007	5610	1102	339	339	206741	154955
1998	178966	29680	12630	1271	328	328	223204	165992
1999	224851	35727	8095	2320	316	316	271626	198653

Appendix Table A12. Total reconstructed catches (in tonnes) for Kenya's freshwater fisheries from 1950-2017, separated by waterbody category and sector.

	Lake Victoria		Lakes, dams and TRD		Rivers		Reconstructed total	FAO reported
Year	**Artisanal**	**Subsistence**	**Artisanal**	**Subsistence**	**Artisanal**	**Subsistence**		
2000	216434	34683	4105	2367	305	305	258198	210343
2001	171239	29185	4942	2504	293	293	208458	156763
2002	132554	32667	5491	2611	282	282	173886	137792
2003	122032	31424	5423	2799	270	270	162218	113221
2004	132721	26540	10767	2828	259	259	173374	119093
2005	153591	28990	4435	2855	248	248	190367	140199
2006	165899	32716	6814	1328	236	236	207229	151729
2007	136051	29539	7613	2835	225	225	176488	124327
2008	129504	28168	10896	1297	213	213	170292	127097
2009	127101	27892	11896	2857	202	202	170149	128036
2010	130740	28155	8592	2831	190	190	170699	131943
2011	155300	30885	5477	2865	179	179	194885	174356
2012	138570	28663	4697	2868	167	167	175134	150131
2013	145243	29390	5982	2868	156	156	183794	154257
2014	149915	29702	7259	2866	144	144	190030	159212
2015	128704	27835	14431	2865	133	133	174101	156468
2016	115515	26913	10196	2863	121	121	155731	127238
2017	109254	26236	6766	2860	110	110	145335	98579
Total	6047452	1210422	431853	94712	43745	43745	7871928	5966140

Appendix Table A13. Data reliability scores separated by category and fishing sector. CWM= catch weighted mean.

	Lake Victoria				**Lakes, dams and Tana River Delta**				**Rivers**				**Total reconstructed**	
Time period	Artisanal		Subsistence		Artisanal		Subsistence		Artisanal		Subsistence			
	Score	± %	Score	± %	Score	± %	Score	± %	Score	± %	Score	± %	CWM	± %
1950-1969	2	30	1	50	2	30	1	50	1	30	1	30	1.7	34
1970-1989	3	20	1	50	2	30	1	50	1	50	1	50	2.5	27
1990-2009	3	20	1	50	3	20	1	50	1	50	1	50	2.7	25
2010-2017	3	20	1	50	4	10	1	50	1	50	1	50	2.7	25
Total													2.6	26