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When 'reality leaves a lot to the imagination': Liberian fisheries from 1950 to 2010

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ABSTRACT

This work is a first attempt to retrace the history of Liberian marine fisheries and estimate total removals by sector for over six decade, thus attempting to address the lack of coherent information on Liberian fisheries. The results, which cover the years 1950 to 2010, revealed strong inconsistencies in the official catch data. Reconstructed total catches for Liberia for 1950-2010 summed to 4.1 million t, which was about 5 times higher than the 337,900 t officially reported by FAO on behalf of Liberia. Officially reported data also exhibited some unrealistic temporal trends, which were corrected in the reconstructed data. Overall, the main insights gained from the present study were the very large amounts of illegal and unreported catches, worth almost $75 US million annually, in the absence of monitoring, and the strength of the impact of civil conflicts on fisheries and food security.

INTRODUCTION

Liberia (6 °N, 9 °W) is a Sub-Saharan West African country bordered by Sierra Leone to the West, Guinea to the North, and the Côte d'Ivoire to the East (Figure 1). Liberia was the only West African country which escaped being ruled by one of Europe's colonial powers. The particular historical path of Liberia lies in the fact that the country was colonized by African Americans (mostly freed slaves called Americano-Liberians) in the early 1800s, and who founded the Republic of Liberia in 1847. Long dominated by Americano-Liberians, Liberia contributed to founding the United Nations and the Organisation of African Unity. A *coup d'état* against the dominance of Americano-Liberians in 1980 plunged the country into a protracted civil war that killed 250,000 people and caused tremendous damage to the Liberian infrastructure (Hendrix and Glaser 2011). As a result, Liberia emerged from this difficult period with 85% of its population below the poverty line and around 20% malnourished, resulting in Liberia ranking 6th among the most malnourished West African countries (Anon. 2013).

A high unemployment rate (85%) caused many Liberians, particularly those living along the coast, to see fisheries as the only option to secure a livelihood (Glasgow 2008). Indeed, more than 80% of the Liberian population depend on fish as a source of protein and/or income.

With an exploitable fish biomass estimated at 180,000 t (NEPAD 2006), the so-called 'Pepper Coast' could generate a sustainable catch sufficient to meet Liberians' need for animal protein, contrary to what is suggested by the low and dubious fisheries catch statistics provided officially (Haakonson 1992). Indeed, in the case of Liberia "The Fisheries Department quite readily admits (unofficially) that its statistics are based on inadequate dubious field data" (Haakonson 1992). Although fisheries statistics in Liberia are probably among the worst on the African continent, it is widely recognized that small-scale fisheries, operated presently by small and mostly non-motorized canoes, play a major role in domestic fish supply. Liberia also "possessed" a fairly large industrial demersal fishing fleet (Smart and Sheves 1979), mostly of foreign origin and either operated under joint ventures, or holding a Liberian flag of convenience, under which vessels do not operate in Liberian waters, but reported as Liberian (Haakonson 1992; NEPAD 2006).

The presence of fisheries instruments and institutions, particularly after the Civil War, was mainly symbolic (Kebe *et al.* 2009), and the fisheries data that any realistic management plan would rely on were scarce, unreliable or completely lacking. The fact that Liberia was never a colony also implied an absence of fisheries resource surveys in the 1950s and 1960s, which contrast with the situation in other West African countries (see e.g., Longhurst 1965). Moreover, "human resources and enforcement capacity are almost non-existent. There has been no government fisheries policy for over a decade and the lame institutions and staffs were not able to guarantee resource conservation" (Kebe *et al.* 2009).

Therefore, although the Food and Agriculture Organization of the United Nations (FAO) appears to have received catch time series from Liberia, and includes over 60 years of landing data in its global database, the catch statistics from Liberia are very doubtful, and the data produced during the civil war are probably imaginary. While the Bureau of National Fisheries (BNF) lacks the proper resources to exhaustively survey fisheries, their services use these officially supplied data for fisheries assessments, which may lead to dangerous conclusions. Moreover, the actual data collection system for artisanal sectors covers only one to three counties of the coast of Liberia with no raising procedure applied, and the number of observer days onboard industrial vessels covers barely 30% of the total time fished (Mees *et al.* 2011). Therefore, the unreliability lies most likely in the under-estimation of marine extractions in Liberian waters. The present work is an attempt to reconstruct an alternative time series of marine catch data, based on the scarce available literature on Liberian fisheries, validated by the anecdotal evidence and gathered knowledge *in situ*.

METHODS

Landing data other than FAO (Fishstat) statistics are very rare; some scattered time series were available through literature referring to national data, pre-war and post-war surveys, or speculative estimates. Data available through the Fishstat provides landing estimates that include both the artisanal and industrial sectors.

Landing data of the Liberian Bureau of National Fisheries were reported for 1981-1988 and 1997-2006 by Haakonson (1992) for artisanal fisheries, and by Glasgow (2008) for industrial fisheries. The comparison between the FAO dataset and the Bureau of National Fisheries data for overlapping years does not show major inconsistencies. However, the artisanal data appear unreliable since they are based on catch reporting from only a few landings sites out of 114, with no further extrapolation. Therefore, artisanal landing data were not used as a baseline in the present study.

Moreover, our review of the literature suggests that, in addition to the artisanal catch, several other catch components must be estimated, i.e., unreported industrial (domestic and foreign) catches; subsistence catches; illegal foreign catches, and discards. Here we reconstruct time series of each of these components, based mainly on the method described by Zeller *et al.* (2007).

Small-scale fisheries

Small-scale catches are grossly under-estimated in Liberia. Only between one and three counties out of a total of nine counties are covered by on-land observers, which represents 7 artisanal landing sites out of 114 in total, and 20% of the canoes, and no country-wide extrapolation are performed. Thus, this situation is similar to that found in Mozambique (Jacquet *et al.* 2010). Small-scale effort data are best reported by ethnic group, as this is a category used by other authors, some of them based on census data or on research- or development-related projects from the early 1950s to 2010 (Table 1). The three major ethnic groups that have been identified here are *Popoh* fishers from Benin and Togo, who use beach seines operated by 8 persons, *Fanti* (and the rarely mentioned *Ewe*) fishers from southwestern Ghana (Mees *et al.* 2011), who use large motorized pirogues of 8 to 17 m, and Liberian *Kru* fishers, who fish mainly for subsistence, and whose canoes are overwhelmingly (92%) un-motorized (Glasgow 2008). Therefore, we assumed that Liberian small-scale fisheries consisted of an artisanal component supplying markets, and represented by the

Popoh and the *Fanti* fisheries, and a subsistence, low capital investment sector represented by the *Kru* fishers, who do supply markets, but to a much lower extent.

Table 1. Fishing effort and CPUE anchor points for 3 ethnic groups in Liberia (all CPUE estimates in t·fisher^{-1}year^{-1}).

Subsistence

Year	*Kru* fishers	Source	*Kru* CPUE	Source
1950	1,030	Estimate	1.1	Assumed 10% higher
1952	1,085	Interpolation	1.1	Interpolation
1960	1,306	Interpolation	1.1	Interpolation
1965	1 445	Dioury (1983)	1.1	Interpolation
1967	1,500	Ssentongo (1987)	1.1	Interpolation
1973	1,162	Interpolation	1.0	Interpolation
1976	994	Dixon and Mingle (1981); Dioury (1983)[a]	1.0	Interpolation
1979	780	Smart and Sheves (1979)	1.0	Interpolation
1981	1,200	Dixon and Mingle (1981)	1.0	Interpolation
1983	960	Lawson and Robinson (1983)	1.0	Interpolation
1985	1,031	Thornes (1986)	1.0	Interpolation
1988	1,000	Ratcliff and Lindley (1988)	1.0	Ratcliff and Lindley (1988)
1991	850	Haakonson (1992)	0.9	Interpolation
1994	1,143	Interpolation	0.9	Interpolation
2008	2,510	Glasgow (2008)	0.5	Interpolation
2010	2,510	Assumed constant	0,5	Assumed 50% lower than 1988

Artisanal

Year	*Fanti* fishers	Source	*Fanti* CPUE	Source	*Popoh* beach-seines	Source
1950	110	Assumed constant	37.40	Assumed 30% lower	0	-
1952	110	van Pel (1954)	38.25	Interpolation	0	-
1960	145	Interpolation	41.62	Interpolation	0	Haakonson (1992)
1965	166	Interpolation	43.73	Interpolation	1	Interpolation
1967	175	Dixon and Mingle (1981)	44.58	Interpolation	2	Interpolation
1973	170	Ssentongo (1987)	47.11	Interpolation	3	Interpolation
1976	211	Interpolation	48.37	Interpolation	4	Interpolation
1979	252	Smart and Sheves (1979)	49.64	Interpolation	5	Interpolation
1981	254	Interpolation	50.48	Interpolation	5	Interpolation
1983	256	Interpolation	51.33	Interpolation	6	Interpolation
1985	259	Interpolation	52.17	Interpolation	6	Interpolation
1988	262	Ratcliff and Lindley (1988)	53.44	Ratcliff and Lindley (1988)	7	Interpolation
1991	52	90% decrease Haakonson (1992)	49.79	Interpolation	8	Interpolation
1994	52	Assumed constant	46.15	Interpolation	11	Interpolation
2008	728	BNF (2013, unpub. data)	29.15	Interpolation	24	Interpolation
2010	728	Assumed constant	26.72	Assumed 50% < than 1988	26	Assumption*

* We assumed the number of *Popoh* beach seines was proportional to the number of *Kru* canoes in 1960, then we used the number of *Kru* canoes in 2010 to derive the number of *Popoh* beach seines;
(a) Effort from frame Survey, adjusted for under-estimation by a factor of the year 1981 (1,200/1,000).

Subsistence fisheries

Kru fishers use mostly small, un-motorized canoes with two to three persons onboard, and a maximum catch per unit of effort (CPUE) estimated at 1 t·canoe^{-1}·year^{-1} (Ratcliff and Lindley 1988). *Kru* fish primarily for subsistence, and the catches are either consumed by the fishers and their families, or exchanged for other types of food. Entry in this fishery requires a low capital investment (Dioury 1983). It is known that, in the 1950s, the major activity of the *Kru* coastal population was subsistence fishing; however, no comprehensive estimates of their fishing effort or catches appears to be available (Schwartz 1974). To estimate the effort in 1950, we derived a *per capita* number of fishers from the first anchor point available, i.e., 4,000 *Kru* fishers (Dioury 1983) over a total Liberian population[1] of 1,280,000 in 1967 (i.e., 0.31%). Therefore, for a population[2] of 824,000 in 1950, the number of *Kru* fishers was estimated at 2,576. Thus, with 2-3 fishers per canoe, the number of canoes in 1950 is estimated at 1,030. We interpolated the number of canoes (Table 1), and assumed their CPUE was 10% higher in 1950 than the 1988 CPUE of 1 t·canoe^{-1}·year^{-1} (Ratcliff and Lindley 1988). For 2010, we assumed a CPUE that was 50% than the 1988 value due to the general pattern of

[1] http://www.bluemarblecitizen.com/people/census-world-Liberia [accessed on February 3, 2013].
[2] http://www.photius.com/rankings/world2050_rank.html [accessed on February 3, 2013].

overexploitation in the area, and the tremendous increase in the number of fishers. We interpolated the CPUE estimates and obtained *Kru* subsistence catches as the product of CPUE and effort.

Lagoon subsistence fisheries

'Inland' fisheries in Liberia are completely unmonitored, but believed to be extremely important for food security (Yevewuo Subah, Deputy Project coordinator, BNF, pers. comm.). This also applies to fisheries in coastal, brackish, lagoonal waters considered here (freshwater fisheries are not considered here). Whether practiced by "Malian migrants or by the Liberian women in almost every household along the shores of lagoons and estuaries, these catches are believed to be high" (Yevewuo Subah, Deputy Project coordinator, BNF, pers. comm.). Here, we will refer to these catches as lagoon catches. Although the FAO Fishstat database shows a time series for inland waters, these are thought to be estimates based on the freshwater component rather than the coastal lagoons. Moreover, the reported inland catch was kept constant for 33 years, including during the civil war, which is unrealistic.

We estimated lagoon fisheries in Liberia using the coastal population data, along with the surface areas of coastal lagoons. We derived the coastal population of Liberia as the population living within 10 km from the coasts from the Center for International Earth Science Information Network database (CIESIN 2012). Three coastal population estimates were available for 1990, 2000 and 2010. We divided the coastal population estimates by the total population (Figure 2, www.populstat.com; www.worldbank.org) to derive the coastal population/total population ratio and assumed this ratio was 10% lower in 1950 compared to 1990, due to increasing migrations towards the coast (see Pauly 2006). We interpolated these ratios, and then multiplied the ratios by the total annual population from 1950 to 2010 (Figure 2). To estimate lagoon catches, we used the method described by Pauly (1976), by applying a catch rate per surface area of the total lagoon area considered here (Figure 3), i.e., lagoons within 10 km from the coast open or closed to the sea. The Liberian coast encompasses many coastal inlets and small lagoons (Ssentongo 1987). Using Google Maps, we identified 30 lagoons for which we estimated the surface area in km^2 (later converted to ha) using GIS. We multiplied the total surface area (18,804 ha) by the catch rate of 150 $kg \cdot ha^{-1} \cdot year^{-1}$ for 1971 (Pauly 1976), and obtained a total catch of 2,821 $t \cdot year^{-1}$ for 1971. We divided the estimated catch by the derived coastal population in 1971 and estimated a catch rate of 19 $kg \cdot capita^{-1} \cdot year^{-1}$. We assumed this rate was 20% higher in 1950 (23.1 $kg \cdot capita^{-1} \cdot year^{-1}$), due to a higher subsistence consumption, and 20% lower in 2010 due to over-exploitation (15 $kg \cdot capita^{-1} \cdot year^{-1}$). Indeed, in Liberia, as in other sub-Saharan African countries, fish consumption seems to have declined (Delgado *et al.* 2003) due to over-exploitation but also to the shift from consumption-based fisheries (subsistence) to trade-based (and most likely export) fisheries. We then interpolated and applied the resulting *per capita* catch rates to the coastal population data and estimated lagoon catches from 1950 to 2010. Given that most targeted species are tilapias (*Oreochromis* spp.), and catfishes (Ariidae) along with other species, we assumed 40% of catches were tilapias, 40% were catfishes and 20% were catches of other fish species.

Artisanal fisheries

Each ethnic category uses different gear: the canoes operated by the *Fanti* range from 8 meters in the past and mostly un-motorized (van Pel 1954) to 17 meter and up to 50 hp today (Ratcliff and Lindley 1988). Ratcliff and Lindley (1988) estimated a catch of 14,000 $t \cdot year^{-1}$ for 262 *Fanti* canoes, i.e., 53 $t \cdot canoe^{-1} \cdot year^{-1}$ for 1988. We assumed the CPUE for the *Fanti* canoes was 30% lower in 1950 because of the lower effort efficiency (van Pel 1954), and decreased by 50% in 2010 due to a generalized over-exploitation pattern (Mees *et al.* 2011).

Haakonson (1992) reported that all maritime fishing activities ceased in 1991 because of the civil war, which also lead to the destruction of fishery infrastructures. The civil war lasted 10-14 years, driving most but not all *Fanti* artisanal fishers, who supplied over 90% of the Liberian artisanal catch, to leave their traditional Liberian fishing grounds (Haakonson 1992; Hendrix and Glaser 2011). Thus, we assumed the *Fanti* effort in 1991 was 80% lower than the effort in 1988, and then we kept the effort constant from 1991 to 2004.

We then performed a series of linear interpolations between the identified effort anchor points (Table 1). We assumed that one *Popoh* beach seine (with 8 fishers) would extract 3.2 times as much as one *Kru* fishing boat (with 2.5 fishers on average), i.e., the *Popoh* CPUE was estimated to be the *Kru* CPUE multiplied by 3.2. We performed a series of linear interpolations to fill the gaps for the effort (For *Popoh* and *Fanti* fishers) and CPUEs (Table 1), then multiplied each category of effort by the corresponding CPUE and estimated total artisanal catches.

Dioury (1983) noted that the existence of a tax on declared canoes made it difficult to trust official surveys data, which tended to under-estimates the real artisanal effort. However, the effort here was kept as estimated, surveyed or reported in the literature sources, which ensures that our estimates remain conservative and thus avoid over-estimating artisanal catches.

Industrial fisheries

Industrial fishing in Liberia began in 1955 (Haakonson 1992). The industrial sector is operated by foreign companies under access agreements, joint ventures with Liberian shell companies or by flying the Liberian flag of convenience (Table 2), due to the large capital investment an industrial vessel requires (Haakonson 1992; NEPAD 2006). The only attempt to truly 'Liberianize' industrial fishing was in 1980, when a company ('Mensurado') went bankrupt after the government took it over (Haakonson 1992). 'Mensurado' was a property of a Liberian official, yet all vessels were of foreign and mostly Greek origin (Larry George, SeaMen Union, pers. comm.). As is the tradition in West Africa, catches are grossly under-estimated as vessels are engaged in unmonitored, offshore transhipping (NEPAD 2006; Glasgow 2008). This practice was widespread and "all industrial vessels were doing that" (Larry George, SEAMEN Union, pers. comm.). Catches were often labeled to Côte d'Ivoire, Senegal, Mauritania, Morocco, and other countries which follow the EU heath standards as they are shipped to Europe. Even the recent presence of poorly paid observers on board is suspected to be "ineffectual"' (Anon. 2008; Glasgow 2008)[3]. Moreover, the recent presence of onboard observers on industrial vessels aimed at scientific research report data that do not match landings observed and reported by inspectors at port. Braimah (2012) showed that around 38% of industrial vessels were under-reporting catches, while Mees *et al.* (2011) showed that the coverage of fishing days by observers was very poor. Moreover, when observers are onboard, they tend to disregard and misreport transhipping practices legalized only recently (Mees *et al.* 2011), and therefore under-report the high catches they imply (Anon. 2008).

Therefore, to estimate industrial catches in Liberian waters, we first estimated the annual CPUE per boat. Mees *et al.* (2011) estimated a CPUE of 6 $t \cdot boat^{-1} \cdot year^{-1}$ in 1998, 2 $t \cdot boat^{-1} \cdot year^{-1}$ in 2010, and we assumed the CPUE was 50% higher in 1950 compared to the 1998 CPUE, i.e., 9 $t \cdot boat^{-1} \cdot year^{-1}$ given documented over-exploitation and over-capacity in the more recent time period. We interpolated linearly the CPUE rates to complete the CPUE time series from 1950 to 2010. We multiplied the CPUE rates by 75% of the 225 authorized fishing days for the industrial fleet, i.e., 169 $days \cdot vessel^{-1} \cdot year^{-1}$ (Mees *et al.* 2011) and estimated the annual CPUEs by multiplying the number of days, assumed constant between 1950 and 2010, by the estimated daily CPUE. Although, many officials claim Liberia has had in the past a proper Liberian fishing fleet, the fact of the matter lies in the fact that a company based in Liberia and owned by a Liberian person operates foreign owned vessels flagged to Liberia. Therefore, to estimate catches by actual country of origin (or true beneficial ownership), we interpolated the available effort per flag data (Table 2) and then estimated the total catch as the product of this effort by the annual CPUE.

[3] In some instances, vessel owners lock observers under deck while pursuing an illegal operation http://www.stopillegalfishing.com/sifnews_article.php?ID=71 [Accessed on February 3, 2013].

Table 2. Summary of reported industrial fishing effort and landings.

Year	Vessels	Notes	Reference	Landings	Reference
1955	0	Industrial fishing started	Haakonson (1992)	0	
1960	7		Ssentongo (1987)	-	
1961	5		Ssentongo (1987)	-	
1962	7		Ssentongo (1987)	-	
1963	7		Ssentongo (1987)	-	
1964	7		Ssentongo (1987)	-	
1965	6	18 foreign vessels (mainly Japanese and Polish, flagged to Liberia) fished from Mauritania to Angola	Ssentongo (1987)	-	
1966	6	3 ex Spanish, and 3 ex Italian	Ssentongo (1987)	-	
1970	7	4 Italian and 3 local	Ssentongo (1987)	-	
1971	32	18 Italian, 3 local, 7 Italian and 4 German	Haakonson (1992); Ssentongo (1987)	-	
1972	10	3 local, 7 Italian	Ssentongo (1987)	-	
1973	3	Local	Ssentongo (1987)	-	
1975	2	Local	Ssentongo (1987)	-	
1977	2	Local	Ssentongo (1987)	-	
1978	10	2 Italian, 2 British, 4 Italian, 2 Angolan, several Soviet and Japanese. Mainly small &medium: 33–140 t	Ssentongo (1987)	4,700	NEPAD (2006)
1980	13		Haakonson (1992)	-	
1981	11		Haakonson (1992)	2,696	Haakonson (1992)
1982	18		Haakonson (1992)	4,244	Haakonson (1992)
1983	24		Haakonson (1992)	5,436	Haakonson (1992)
1984	25		Haakonson (1992)	4,671	Haakonson (1992)
1985	13		Haakonson (1992)	1,709	Haakonson (1992)
1986	34		Haakonson (1992)	7,339	Haakonson (1992)
1987	29		Haakonson (1992)	6,765	Haakonson (1992)
1988	45	Including joint ventures that are not operating in Liberia	Haakonson (1992)	5,170	Haakonson (1992)
1997	-			1,579	Glasgow (2008)
1998	-			2,700	Glasgow (2008)
1999	-			4,493	Glasgow (2008)
2000	-			2,425	Glasgow (2008)
2001	-			2,239	Glasgow (2008)
2002	-			2,201	Glasgow (2008)
2003	-			2,020	Glasgow (2008)
2004	-			3,191	Glasgow (2008)
2004	-			3,584	Glasgow (2008)
2006	40		Glasgow (2008)	2,894	Glasgow (2008)
2008	38		Glasgow (2008)	1,089	Glasgow (2008)
2010	50		Braimah (2012)		

We then applied the species breakdown provided for industrial fisheries by Glasgow (2008) for the 2000s (Table 3). Pair-trawlers are known to catch more fish, therefore, we separately added the authorized Chinese pair-trawlers since 2003. Around 8 Chinese pair-trawlers were authorized to fish in 2007 (USAID 2008), before the ban of pair-trawling, while the number of authorized Chinese trawlers was 4 in 2010/2011 (Thiao 2011). We interpolated linearly from zero in 2003 when China started fishing legally in Liberia. We then applied the CPUE of 1,200 $t \cdot boat^{-1} \cdot year^{-1}$ estimated by Pauly *et al.* (2013) for trawlers and estimated total Chinese legal catches.

Unregulated/Illegal fishing

Here, unregulated fishing is defined as unlicensed industrial foreign fishing within the Liberian equivalent EEZ waters prior the establishment of the EEZ in 2008, while illegal fishing is defined as unlicensed fishing within the Liberian EEZ after 2008, and in territorial waters of Liberia at any time. MRAG (2005) estimated illegal fishing to be 59.4% of total catches, i.e., 146% of landed catches for about 150 to 200 vessels, of which 53% were targeting tuna species. Braimah (2012) reported the total number of illegal vessels at 200 to 300. It is noted that the monitoring capacity of Liberia before, during and after the civil war were almost non-existent (MRAG 2005). McConnell (2008) reported some 250 boats fishing illegally in Liberian waters, including trawlers from China, South Korea, Spain, Portugal and Greece, and large motorized pirogues from Senegal and Ghana. To estimate total unregulated/illegal catches, we assumed the rate of unregulated fishing was a third in 1950-1988, i.e., 49%, then increased to 146% of landings in 2005 due to the lack of monitoring

during the civil war. We then separately estimated Chinese illegal fishing, since effort data for the later was available, with 8 pair-trawlers fishing illegally in Liberian waters from 2008 to 2010 (Glasgow 2008). It is fair to assume Chinese illegal fishing started in 1990 at the beginning of the civil war, taking advantage of the complete absence of governance structure (Agnew *et al.* 2009) on the one hand, and the expansion of the Chinese distant water fleet on the other hand. We interpolated the fishing effort, then multiplied the latter by a CPUE of 1,200 $t \cdot boat^{-1} \cdot year^{-1}$ (Pauly *et al.* 2013), which would correspond to a higher catch by pair trawlers. Then we allocated the difference between the total illegal catch and the Chinese illegal catch to the remaining countries, assuming Ghana represented 30% from 1950 to 1988 prior the beginning of the civil war, then decreased to 25% in 2010, Senegal with 10% from 1950 to 1988, increasing to 15% in 2010, and the remaining allocated evenly between Spain, Portugal, Greece and South Korea (McConnell 2008).

Table 3. Artisanal catch composition in 1979 based on records of the National Bureau of Fisheries, Monrovia, and industrial catches based on Glasgow (2008)

Taxon name	Artisanal (%)	Industrial (%)
Clupeidae	52.35	10.41
Bonito, tuna and billfish	10.17	-
Pseudotolithus spp.	5.56	7.97
Cynoglossus spp.	5.28	-
Other marine fish	5.09	-
Sphyraena spp.	4.62	-
Various sharks	4.20	0.01
Caranx spp.	4.10	-
Trachurus spp.	2.72	4.25
Arius spp.	2.19	1.93
Sparidae	1.50	-
Galeoides decadactylus	0.63	-
Epinephelus spp.	0.29	<0.01
Lutjanidae	0.29	<0.01
Pentanemus quinquarius	0.24	-
Sciaenidae	0.22	-
Mugilidae	0.17	-
Rays and skates (Rajiformes)	0.17	0.13
Palinuridae (lobsters)	0.07	-
Pomadasys	0.06	5.48
Polydactylus quadrifilis	0.05	-
Marine crabs	0.01	-
Trichiurus lepturus	0.01	-
Lutjanus spp.	-	18.98
Osteichithyes	-	14.5
Stromateus fiatola	-	9.75
Soleidae	-	8.10
Scomber japonicus	-	5.51
small mixed fish	-	3.57
Brotula barbata	-	2.47
Congridae	-	1.79
Sardinella melanura	-	1.56
Sphyraena spp.	-	1.48
Nantantia	-	1.32
Thunnus albacares	-	0.46
Albula vulpes	-	0.13
Brachyura spp.	-	0.05
Drepane africana	-	0.05
Palinurus spp.	-	0.04
Lutjanus johnii	-	0.01
Sepiidae	-	0.01
Octopodidae	-	0.01
Balistidae	-	0.01
Thunnus obesus	-	0.001

Discards

Based on at-sea observation, discards of the industrial fleet were estimated at 30% of total catches (Glasgow 2008), i.e., 42% of landings, also observed by crew members in the industrial fleet's (Larry George, SEAMEN Union, pers. comm.). Therefore, we applied this rate to the total estimated industrial catch from 1955, when industrial fishing began to 2010.

This rate is low compared to the neighbouring countries and common industrial fleet practices. This is justified by the fact that "low value by-catch, normally discarded, are rather given to artisanal fishers in exchange of fruits. This, along with the landing of what is called "local fish", mostly low-value species, small size barracudas, sardinellas, and 'trash-fish', was normal routine" (Larry George, SEAMEN Union, pers. comm.), and was practiced to cover for fuel cost and support fishing operations on the ground (Yevewuo Subah, Deputy Project coordinator, BNF, pers. comm.). We applied a similar discard rate to the illegal industrial fleets from South Korea, Spain, Portugal and Greece and a higher discard rate to the Chinese illegal pair-trawling fleet (Larry George, SEAMEN Union, pers. comm.), estimated at 80% of catches (Yevewuo Subah, Deputy Project coordinator, BNF).

RESULTS

Small-scale catches

Subsistence

Reconstructed subsistence catches from the ocean accounted for 73,600 t for 1950 to 2010 (Figure 4a). They remained relatively stable during the 1950-2010 time period, at an average of around 1,300 t·year^{-1}. However, there were fluctuations, notably a decrease from the 1970s to the early 1990s, followed by an increase starting during the civil war, to a maximum of 1,400 t·year^{-1} in 2008 (Figure 4a).

Lagoon catches were estimated at over 228,000 t between 1950 and 2010. Lagoon catches increased from 1,900 t·year^{-1} in 1950 to 4,400 t·year^{-1} in 1985, after which catches declined slightly to 3,970 t·year^{-1} at the beginning of the war, then catches increased rapidly to a maximum of 7,100 t·year^{-1} in 2010 (Figure 4a).

Artisanal

Reconstructed artisanal catches accounted for 480,000 t between 1950 and 2010 (Figure 4b). They increased from around 4,000 t·year^{-1} in 1950 to a peak of around 14,000 t·year^{-1} in the late 1980s, then decreased dramatically during the civil war to a minimum of 1,800 t·year^{-1} in 2004 (Figure 4b). Artisanal catches increased thereafter to 19,500 t·year^{-1} in 2010 (Figure 4b).

Industrial legal catches

Reconstructed legal industrial catches taken by essentially foreign vessels in Liberia amounted to 1.3 million t for 1950-2010 (Figure 5a). These catches increased from near zero in 1955 to a peak of around 46,100 t·year^{-1} in 1990, right before the beginning of the civil war (Figure 5a). Industrial legal catches decreased thereafter to 28,000 t·year^{-1} in 2004 with the decrease in the number of licensed vessels, and then remained relatively constant at 27,200 t·year^{-1} (Figure 5a). Overall, catches by Western European countries dominated between 1950 and 2010 (Figure 5b), however, the contribution to legal industrial fishing activities shifted to be dominated by Asian countries after the war, notably by South Korea (26%) and China (21%).

Discards

Discards of the legal fleets totalled over 527,000 t between 1950 and 2010, representing 21% of the reconstructed legal catch, while it represented the equivalent of 67% of the truly domestic catch (mainly small-scale). Discards followed the same pattern as industrial catches, given the method used for the estimation of discards (Figure 5a). Discards peaked at 19,300 t·year^{-1} in 1990, then decreased gradually to less than 11,400 t·year^{-1} in 2010 (Figure 5a).

Industrial unregulated/illegal catches and discards

Unregulated and illegal foreign catches were estimated at 1.3 million t between 1950 and 2010, which is the equivalent of 49% of the catches generated by the legal sector and 60% higher than the actual Liberian domestic catch (i.e., the catches of the artisanal and

subsistence fisheries). Unregulated and illegal catches increased from 2,600 t·year^{-1} in 1950 to a maximum of around 52,800 t·year^{-1} in 2005 after the end of the civil war. Illegal catches decreased thereafter to 11,500 t·year^{-1} in 2010 (Figure 6). During the 1950-2010 time period, Ghana was responsible for the bulk of illegal catches with 24% (151,000 t). However, when only the post-civil war period is considered, China, whose illegal activities started at the beginning of the civil war, turned out to be responsible for around 40% of the illegal catch (Figure 6). Unregulated and illegal catches followed the same pattern as the legal industrial catch until the beginning of the civil war, when the legal component decreased and the unregulated/illegal catches increased (Figure 7).

Discards generated by illegal fleets were estimated at 249,000 t over the period between 1950 and 2010. Discards by illegal fleets increased from around 300 t·year^{-1} in 1950 to a peak of 14,000 t·year^{-1} in 2005 driven by high discards by China, with over 50% of total discards by illegal fleets.

Reconstructed total catches

Total removals from Liberian waters were estimated at 4.1 million t from 1950 to 2010, of which 782,000 t were caught by small-scale artisanal and subsistence fisheries (Figure 8). The small-scale sectors represent the truly Liberian domestic fisheries catch made available to the Liberian population. This sector alone is 66% higher than the data supplied by Liberia to FAO (337,900 t) considering the marine component, and twice as high as the FAO landing data after accounting for the lagoon catches. The legal industrial sector accounted for around 1.8 million t, while the unregulated/illegal foreign catch was responsible for over 1.3 million t between 1950 and 2010, along with 249,000 t of illegal discards. Total removals from Liberian waters increased from around 9,900 t·year^{-1} in 1950 to a peak of about 112,000 t·year^{-1} in 1988, then decreased to around 89,000 t·year^{-1} in 2010 (Figure 8a). Taxonomically, although over 140 taxonomic groups were identified and caught by the different sectors operating in Liberia, catfishes and small pelagic fishes such as clupeoids dominated catches (Figure 8b).

DISCUSSION

This work is the first attempt to obtain a realistic overview of fisheries catches in Liberian waters. Total reconstructed (legal) catches were estimated at 2.6 million t between 1950 and 2010, compared to the 337,900 t reported by FAO on behalf of Liberia. Total removals from Liberian waters included 480,000 t of artisanal catches of *Popoh* and *Fanti* origin, 74,000 t of subsistence *Kru* catches, 228,000 t of lagoon and brackish-water catches, 550,000 t of industrial catches (essentially foreign), associated with discards of 527,000 t, and a very high illegal foreign catch and their corresponding discards estimated at 1.5 million t between 1950 and 2010, of which 22% was Ghanaian and 16% Chinese. Although the methods utilized here were conservative, and using low CPUEs for the artisanal and industrial sectors (see Mees *et al.* 2011), the results showed that official data reported by FAO on behalf of Liberia (including only what is considered domestic and legal) was under-estimated by a factor of 5 (only considering marine catches).

The methods, assumptions and results found in the present study were validated in country by the BNF during a short stay in Liberia in April 2013. Furthermore, the artisanal catch estimation method estimated a likely catch about 4 times higher than the reported landing data supplied by the BNF, which is comparable to the extrapolation factor estimated using BNF effort data. Indeed, the BNF effort data classified into two categories of effort, Liberia (*Kru*) and foreign (Ghanaian), in nine counties, for only one county covered partially, when multiplied by the respective CPUEs derive an extrapolation factor of 3.65 (excluding the *Popoh* artisanal fishers).

Total legal removals from Liberia increased from around 5,000 t·year^{-1} in 1950 to a peak of around 76,400 t·year^{-1} in 1989. Thereafter, catches decreased during the Civil War to around 43,000 t·year^{-1} in 2003. Around 28,000 t·year^{-1} were caught and 12,000 t·year^{-1} discarded by foreign vessels operating in Liberian waters. During the same time, only 9,000 t·year^{-1} were

made available for consumption by Liberians, mostly from lagoons and brackish waters. This further illustrates how social and political conflicts have a direct impact on fisheries (Agnew *et al.* 2009; Hendrix and Glaser 2011). Furthermore, while artisanal catches were strongly impacted by the war, with minimal catches during the worst of this period, industrial fisheries flourished and caught much more than what was estimated by BNF from different sources, with most being exported to foreign markets. It is also demonstrated by the present study that the lack of governance, monitoring and control encouraged illegal industrial fishing, which caught over 40,000 t of fish annually during the civil war.

The present study shows a staggering lack of reliable information on Liberian fisheries. For example, while scientific research shows that the artisanal sector collapsed to 10% of its previous size during the civil war (Haakonson 1992), official data do not reflect the impact of the civil war on artisanal catches. Furthermore, given the mandated requirement of FAO to rely on data reported to it by member countries, industrial catches from vessels flying the Liberian flag as a flag of convenience during the civil war would have been incorporated into the FAO data for Liberia. These were not considered in the present study, since we only addressed catches from Liberian waters. Therefore, it is reasonable to conclude that landings data reported by FAO on behalf of Liberia may over-estimate Liberian artisanal catches in Liberian waters during the civil war.

Overall, the absence of a legal system for fisheries monitoring, the absence of a proper statistical system and lack of awareness about the informal small-scale fishery led to the official under-estimation of catches in Liberia. This study also shows a shift from legal to illegal operations. The legal industrial sector decreased and the unregulated/illegal sector increased during the civil war, while one would suspect that the same vessels would stay in the same fishing grounds in the absence of monitoring and control. This is revealed to be true, as Chinese pair trawlers were banned from Liberian waters, yet they were strongly suspected to operate illegally, operating from bases in Guinea or Sierra Leone.

Industrial catches estimated here are likely conservative, given the low CPUE compared to formal trawl surveys (see Mees *et al.* 2011). Yet, considering a market price of $2000 US per tonne (Mees *et al.* 2011), the value of the unmonitored legal and illegal industrial catches was herein estimated at over $74.8 US million annually, most if it lost to Liberia. Illegal (unauthorized) fishing alone is responsible for the loss of $23 US million, which is doubling the previous estimates of 10-$12 US million (www.stopillegalfishing.com). The economic loss generated by these fisheries would be accentuated by considering the fishing opportunities lost for artisanal fishers. This loss of fishing opportunities is generated by decreasing yet still high conflict occurrence and over-fishing leading to decreasing catch rates.

Liberia remains, however, one of the very few African countries that demonstrate a clear improvement in both conflict reduction between artisanal and industrial fisheries and tackling illegal fishing practices. Indeed, the Liberian government answered to the increasing conflicts between artisanal and industrial fleets by increasing the size of the areas reserved for artisanal fishing. Monitoring has also strongly increased in the two last years (not covered in the present study). Under-reporting of legal industrial catches is also believed to have decreased drastically, since nowadays all industrial vessels have observers onboard, at sea trans-shipments (now legal) are reported, as are discards (including garbage, plastic and fishing nets), and landings. The very fact that there are more at sea-observers than fisheries inspectors on land shows an improvement in industrial data reporting.

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FIGURES

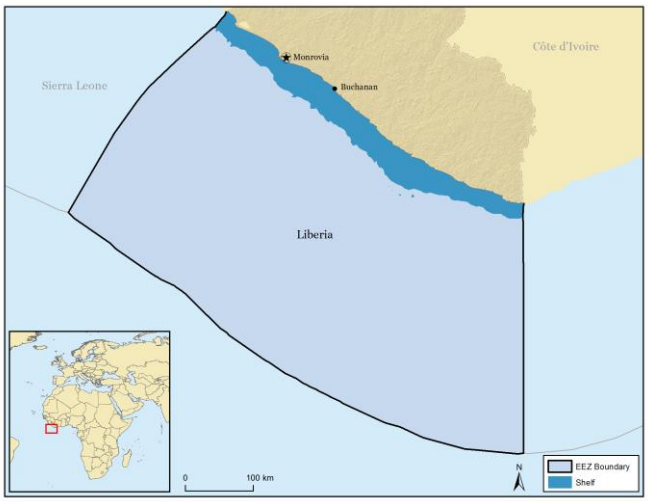

Figure 1. The Exclusive Economic Zone (EEZ) and shelf area (to 200 m depth) of Liberia

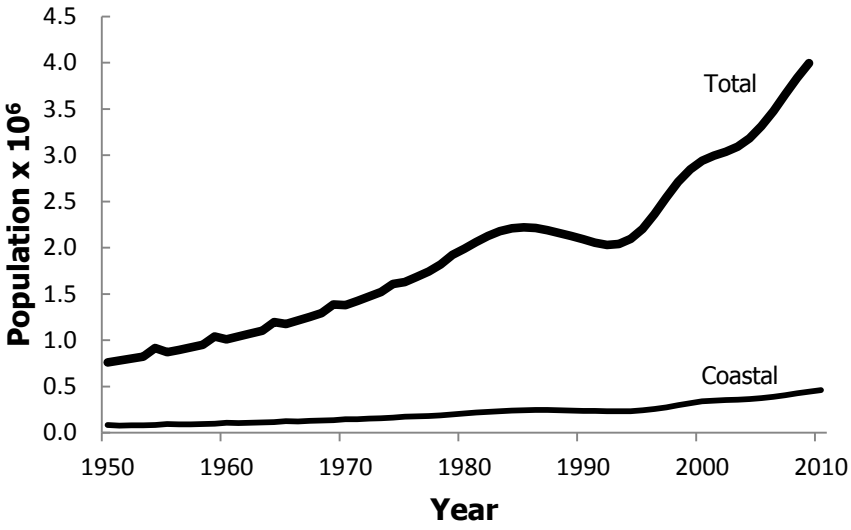

Figure 2. Total and coastal population of Liberia, 1950-2010.

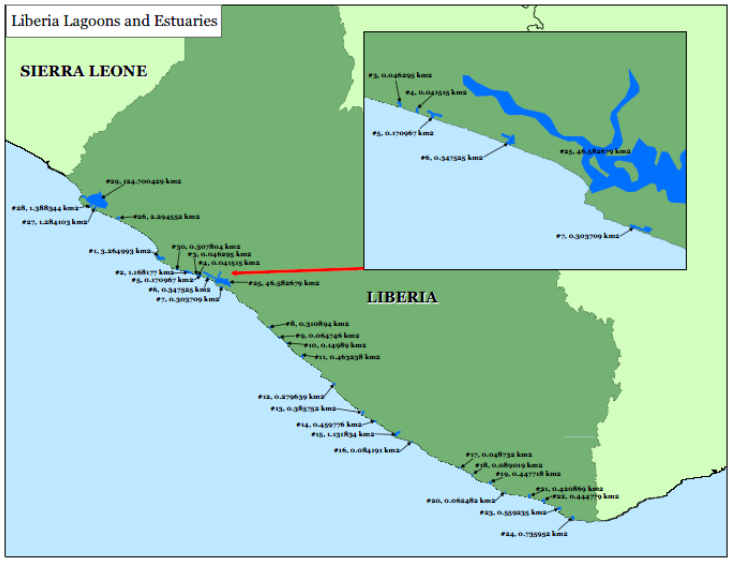

Figure 3. Map of Liberia showing coastal lagoons

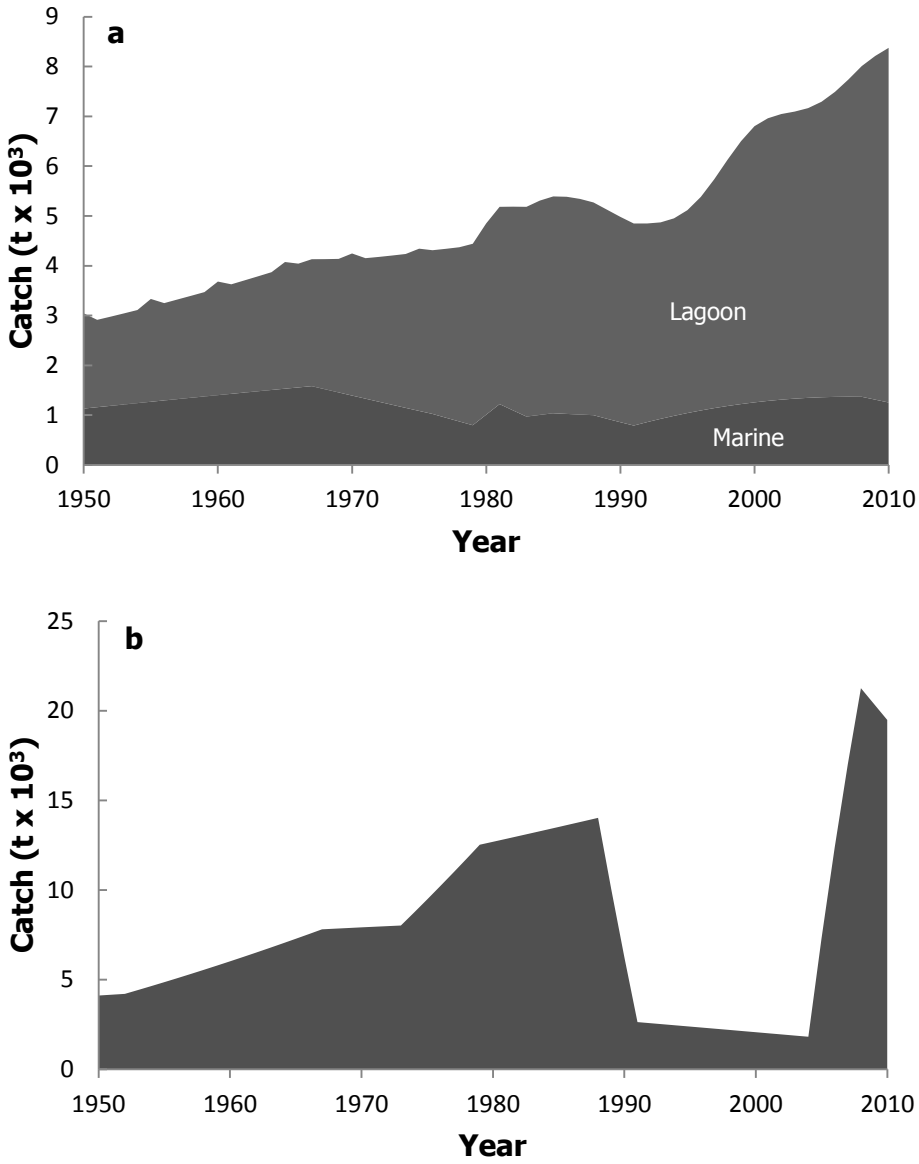

Figure 4. Reconstructed Liberian small-scale catches including (a) marine subsistence (*Kru*) catches and lagoon subsistence catches, and (b) artisanal (*Fanti* and *Popoh*) catches, 1950-2010.

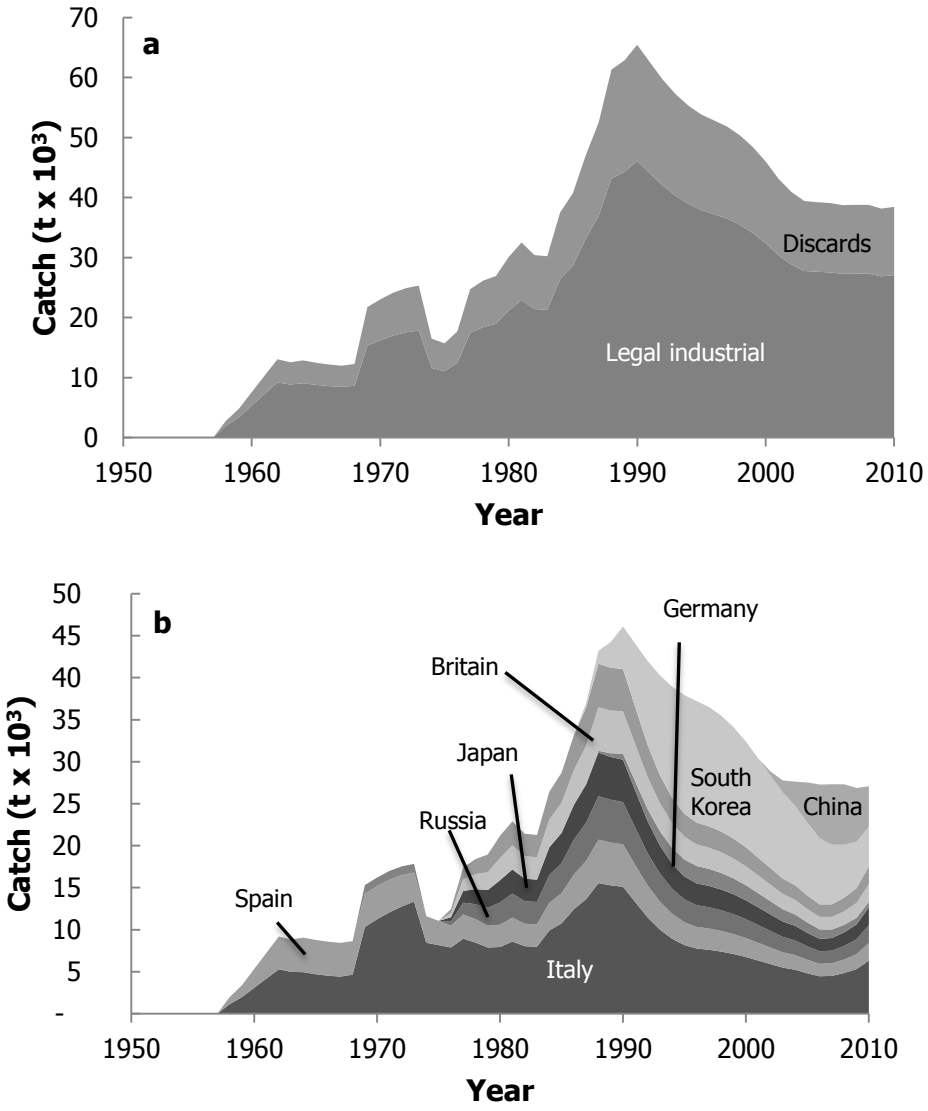

Figure 5. Reconstructed catches generated by the legal industrial sector from Liberia, by a) landings versus discards and b) by country of origin, 1950-2010.

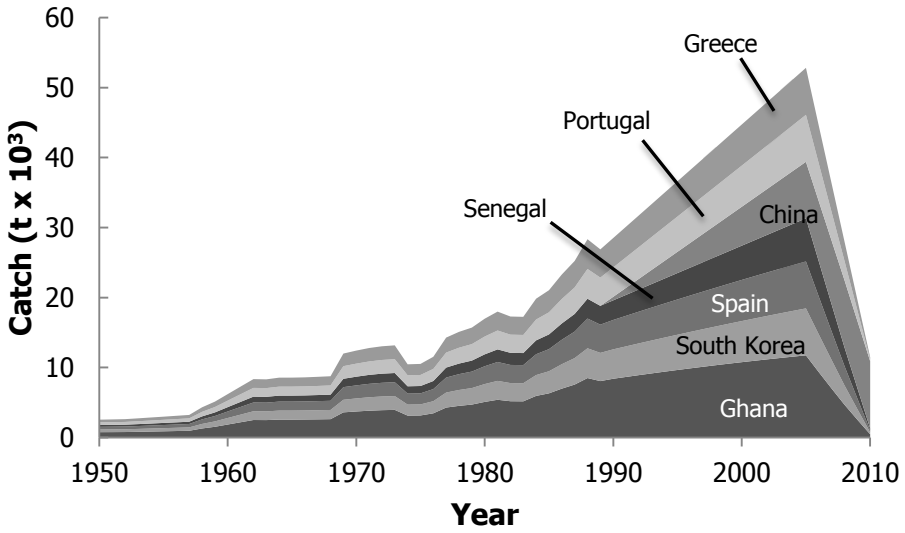

Figure 6. Total reconstructed unregulated and illegal foreign catches from the waters of Liberia, 1950-2010, by fishing country. This figure excludes discards.

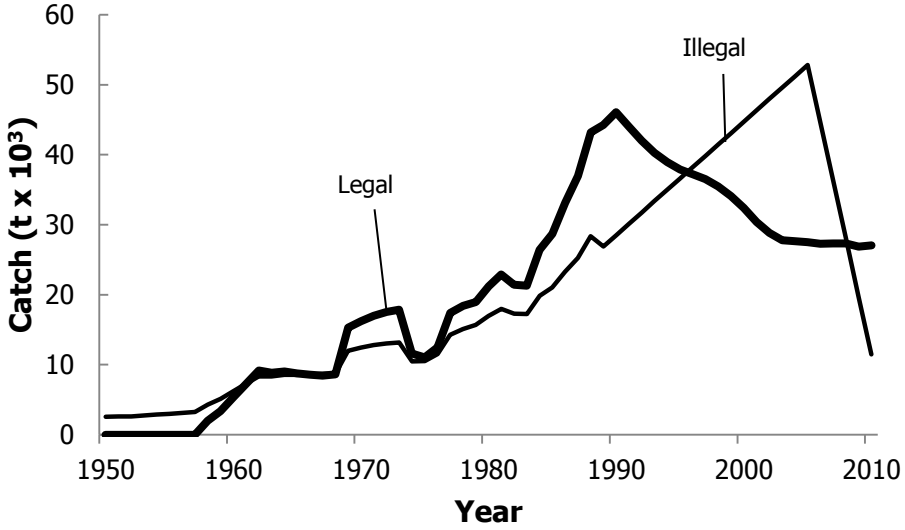

Figure 7. Reconstructed legal industrial catches compared to the unregulated and illegal foreign catches from Liberian waters, 1950-2010. These figures do not include discards

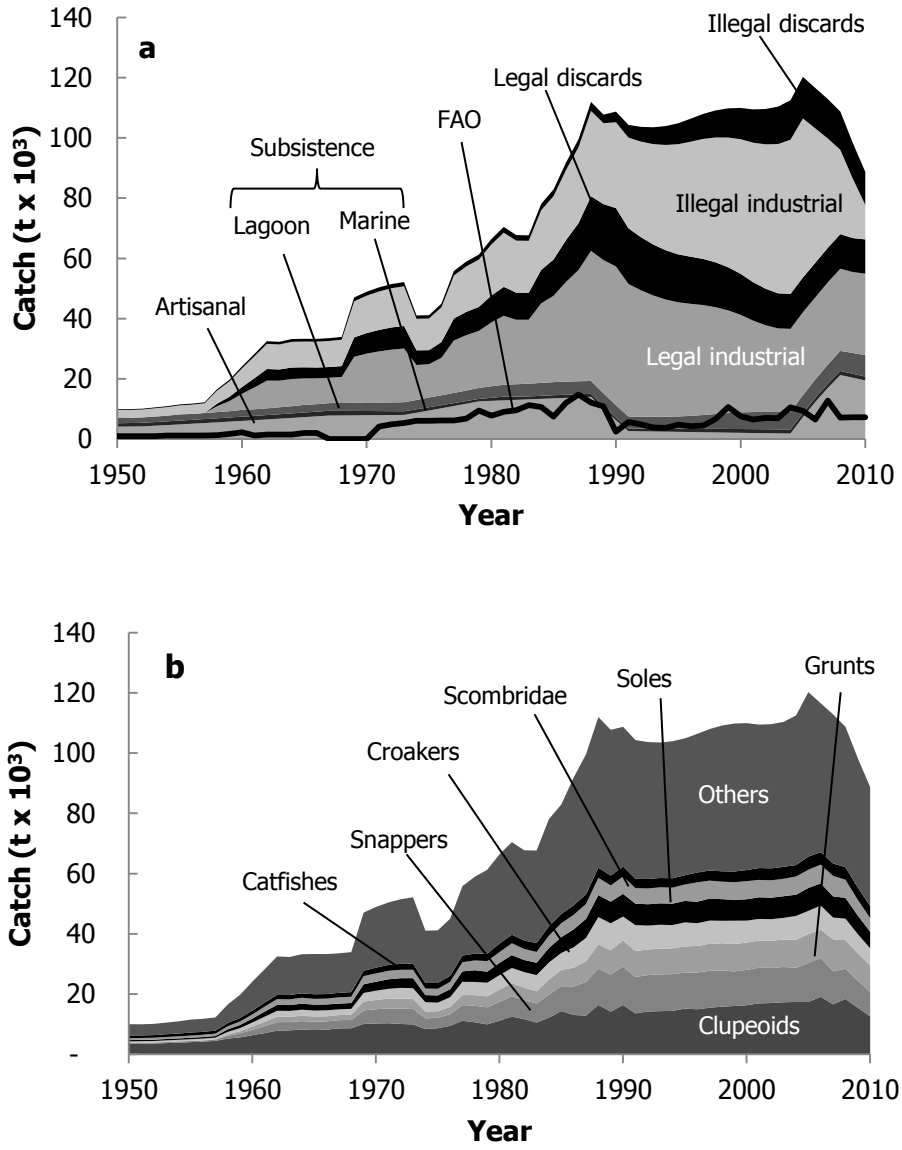

Figure 8. Reconstructed marine catches for Liberia by a) fishing sectors. Note that the data officially reported by FAO on behalf of Liberia is overlaid as line graph; and b) taxon, 1950-2010.