The Gambian Sole Stock Assessment
Final Report

Gambia-Senegal Sustainable Fisheries Project (USAID/BaNafaa)

2012

Cover Photo: Catching sole (Left photo), Sole catches (Center), Processing sole plant (Left)

Photo Credit: Kathleen Castro, Gibril Gabis and Lina Kelpsaite**,** USAID/BaNafaa project/World Wide Fund for Nature-West Africa Marine Program Office (WWF-WAMPO).

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INTRODUCTION

This stock assessment has been undertaken as part of the USAID- BaNafaa Project. Several studies of the sole resource and fishery have occurred previous to and concurrently with this assessment. These include a species identification survey, bycatch and gillnet characterization, gillnet selection, length-weight analyses, age and growth study, landings surveys (length frequency) and a local knowledge summary. A sole management plan has resulted from these efforts that was developed in a co-management process. A first stock assessment was performed on the Gambian sole as part of a MSC pre-assessment (Medley et al., 2008) establishing a partial baseline. With the new information gained from the USAID-BaNafaa Project , this is the second stock assessment was conducted as a collaborative effort between staff from the University of Rhode Island Fisheries Center and the Gambian Department of Fisheries.

Although about nine species of flat fish are reported to inhabit the coastal waters of Gambia, two species predominate the catch and landings: red sole (*Cynoglossus senegalensis)* and black sole (*Synaptura cadenati)* (CRC, 2011). These species inhabit a wide area of the eastern-central Atlantic from Mauritania to Guinea (Fishbase, 2012). It is unknown if there are specific or unique stocks of these resources that inhabit the coastal water of the Gambia, but it must be recognized that the coastline of the Gambia is small, and is surrounded by the much larger coastline of Senegal. Both species of these flatfish are harvested in the Gambia and Senegal, and it is likely a shared resource. So, while the red and black soles of the Gambia may be considered a management unit for the Gambia, from a fish population dynamics perspective the entire stock must be defined, and landings and effort for the entire stock must be used to conduct a complete stock assessment of the resource. Thus, the purpose of this report is to summarize what is known for the resource in the Gambia: landings, catch per unit effort (CPUE), and the estimation of fishing mortality and reference points for the management unit landed in the Gambia.

Summary of Landings

Landings of all species sole fish are aggregated by the Department of Fisheries (DoFish) in the Gambia and are reported as either artisanal or industrial (Figure 1).
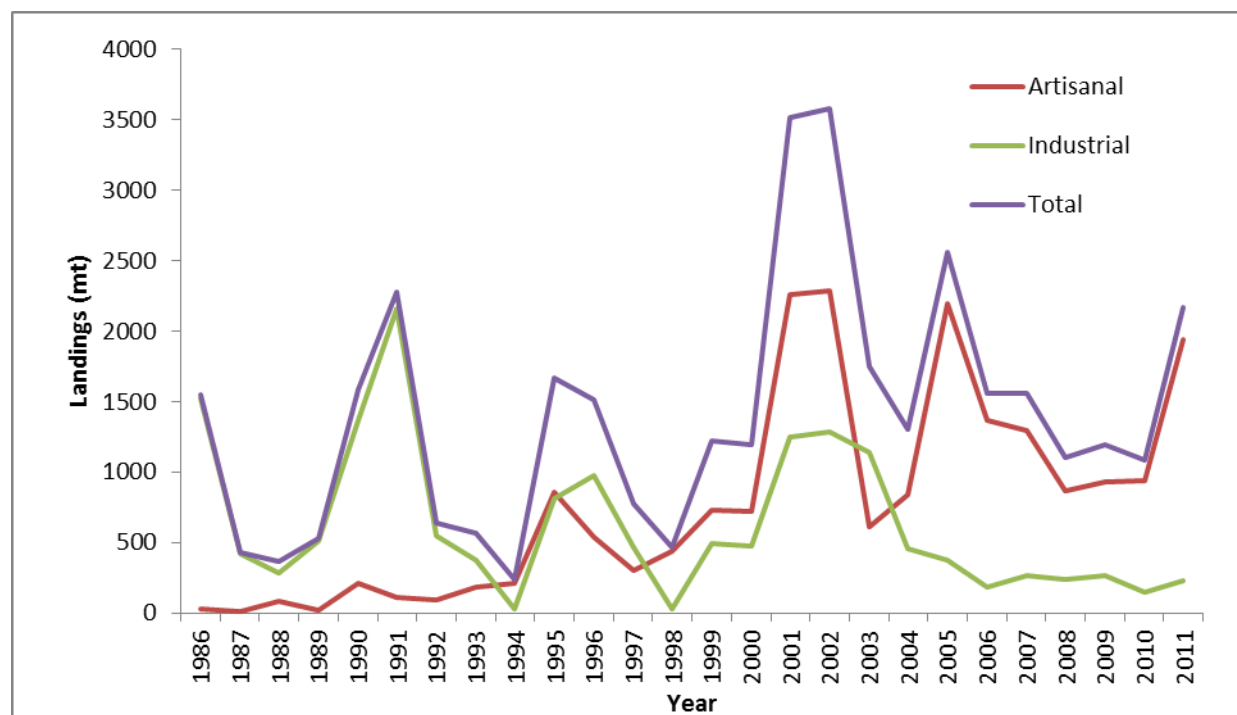
Figure 1: Reported landings by artisanal and industrial sectors of mixed sole fish in the Gambia in metric tons (mt) from 1986 to 2011.

Artisanal landing have slowly increased in the last 25 years with several major peaks followed by declines in 1995, 2001/2002 and 2005. Current landings by the artisanal fishery are about 1500 mt annually. In contrast, landings of the industrial fishery have slowly declined in the last 25 years with peaks in 1991, 1996 2001/2002. The current harvest of sole by the industrial fishery is about 200 mt annually, and these fish are landed in Senegal. The data on sole fish harvested by the industrial fishery in the Gambia are collected by Gambian observers on the trawlers. As a basis for comparison landings of red sole alone in Senegal were 10,000 to 15,000 mt in the period 1992 to 1994, and in the early 2000s averaged 4,000-5,000 mt according to the Agence Japonaise de Cooperation Internationale (2006). Clearly, sole landings by artisanal fishermen in the Gambia are only a small portion of the removals from the sole resource if it is a single stock shared with Senegal.

ESTIMATION OF CATCH PER UNIT EFFORT

Introduction

A catch per unit effort (CPUE) index is a critical input into a fish stock assessment. It provides a relative index of abundance and when combined with catch data for the stock can be used in a surplus productions model to estimate a trajectory of stock biomass and exploitation. In Gambia, there is an abundance of data on the fisheries that has been collected over the last two decades, but only landings data is conveniently accessible for analysis. This section of this report presents the results of our effort to develop a fishery based CPUE index for the sole fish resource. While there are several species of sole that are harvested in the artisanal and industrial fisheries of the Gambia, two species dominate the catch: red sole (*Cynoglossus senegalensis)* and black sole (*Synaptura cadenati).* The Gambia fisheries statistics only note a species group in the landings, and that is referred to as sole fish. It has been reported by local artisanal fishermen that the red and black sole are spatially segregated in the coastal waters with black sole further offshore than red sole (Drammeh, et al, 2011). As the industrial trawl vessels are supposed to operate outside of 9 nm, the catches of the trawlers may not completely reflect the red sole abundance.

The artisanal fishery that uses a bottom set tangle/gill net accounts for the majority of the sole fish landings in the Gambia. Artisanal landings are estimated based on a sampling procedure that accounts for various landing sites, fishing days and the number of boats fishing. However, a portion of the landings is taken by the industrial trawlers working off the coast in the Atlantic stratum and landed in Senegal. In the past, only the catches of these trawlers have been reported, but in the paper records that have been collected by the Industrial Fishery Sector group at DoFish, there is effort data summarized by hours and days fishing by month for each fishing trawler operating in Gambian water. These vessels all have independent fishery observers on board, and they collect the data and report the catch data daily by radio to DoFish in Banjul. The monthly summaries of the original data tabulate the total catch of sole (kg), total effort (hours and days fishing), catch per unit effort (kg/h and kg/d) for the years 1998 to 2011. In a typical year there may have been 15 to 30 vessels with catch data reported daily, and totaled for the month and year. These trawlers target shrimp, and the entire demersal complex, and sole is considered a bycatch that is retained and sold.

The artisanal and industrial sole catch data when compared to the appropriate effort data required to capture the fish can potentially provide an index of relative abundance for the sole fish resource. The artisanal index may be representative of both species of

sole, whereas the industrial index may be more appropriate for the black sole as noted previously.

Methods

For the artisanal index, the original paper port sampling records for 2008 through 2011 were available for review. The catch of individual sampled boats and the days fishing were extracted and summed for each year. The CPUE index for each year was estimated by dividing the total catch by the days of effort. Neither the landings nor the effort are complete for the fishery, but are considered to be a representative sample of the fishery. Regression analysis was conducted on CPUE versus time to test the significance of the trend in CPUE.

For the industrial fishery, the original paper records were reviewed, and the data on sole catch and effort by vessel by year were extracted and entered into an EXCEL spreadsheet. The entered data were reviewed, and independently compared to the original data. For each vessel, an annual CPUE was calculated, then the annual catch and effort data by vessel were summed, and finally an annual CPUE was calculated. Data were not available for 2003 and 2007 as the paper files were missing, and these were estimated by extrapolation from the published industrial catch data for sole. The summed catch data were compared to the published catch data for the industrial sector. However in that time series, the 2002 catch data for sole is missing, so the summed catch data from the original paper records was substituted. All results were plotted as time series for presentation and interpretation purposes. Regression analysis was conducted on CPUE versus time to test the significance of the trend in CPUE.

Results

For the artisanal fishery, the CPUE index is shown in Figure 2 for the period 2008 to 2011. While there does appear to be a slight positive trend in the CPUE with time, the slope is not significant different from zero. It is interesting to note that the mean CPUE for the artisanal fishery is about 50 kg per day of fishing, and this is consistent with reports of the catch rates for the artisanal fishery in the MSC Sustainable Fisheries Certification Report (2008). However, it is has been reported that there has been changes in the nets used in the artisanal fishery and this may have changed the catchability of the gear, thus effecting the CPUE index (Gabis et al 2011a)

For the industrial fishery, the data collected and summarized are listed in Table 1. The highlighted cells represent data that was estimated by either interpolation or by substitution. The time series of annual industrial fishery sole catch (kg) and effort (days) is shown Figure 3. There appears to be a strong correlation between increasing

catches and increasing effort. The summed annual reported industrial vessel sole catch was compared to the published annual industrial sole catch in Figure 4, and there is good agreement in the catch data, suggesting confidence in further analysis. The industrial CPUE index (kg/day) for sole fish taken by dividing the annual reported catch by the effort that was required to produce that catch is shown in
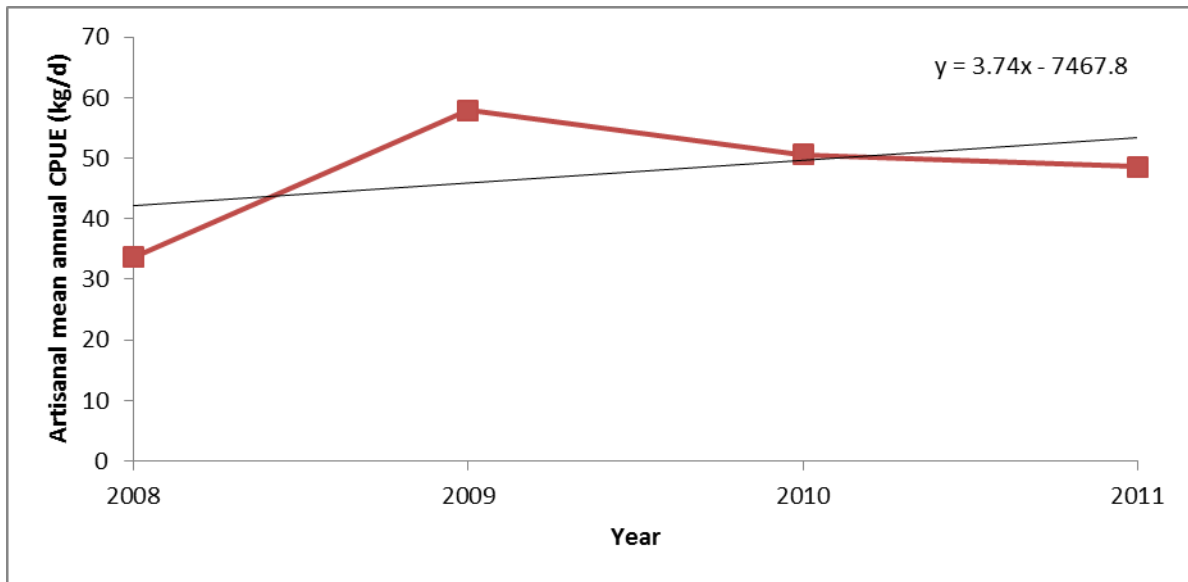
Figure 2: Mean annual CPUE (kg/day) for sole fish in artisanal fishery in Gambian waters.

Figure 5. Recall that this can be relative index of abundance for the sole resource, and it indicates considerable temporal variation in sole stock abundance over the observation period, 1998 to 2011. During the period 1998-2000 and again in 2009, sole stock abundance was relatively low, but during the periods 2001-2008 and 2011, sole stock abundance was relatively high. The mean CPUE for sole fish by the industrial fishery in the Gambia is about 150 kg/day. The trend in CPUE is slightly negative, but again the slope is not significantly different from zero, so in fact there is no long term trend in CPUE or relative abundance.

These CPUE indices of abundance could be used as potential inputs to a biomass dynamic, surplus production model to estimate the absolute abundance of the sole resource, level of exploitation, and management reference points for sole fish species group. However to accomplish this, the stock must be defined, complete landings or removals from the stock from all sources must be summed, and ideally these Gambian artisanal and industrial fishery CPUE indices would be used along with other CPUE indices as input to the assessment model.

Year	Catch	Effort (h)	Effort (d)	CPUE(kg/h)	CPUE(kg/d)	Ind Landings (kg)
1998	321407	49291	3279	6.5	98.0	29670
1999	485723	82634	5490	5.9	88.5	490884
2000	636192	104456	6378	6.1	99.7	471736
2001	1597007	106646	6349	15.0	251.5	1250000
2002	1289248	101323	5830	12.7	221.1	1289248
2003	1139287	87000	5000	13.1	227.9	1139287
2004	623258	74612	4381	8.4	142.3	461900
2005	367118	36812	2253	10.0	162.9	371300
2006	188019	26730	1269	7.0	148.2	188100
2007	310049		2388		129.8	264040
2008	276222	26298	1553	10.5	177.9	242460
2009	97463	23589	1435	4.1	67.9	266700
2010	198397	32948	1939	6.0	102.3	147000
2011	397527	36737	2167	10.8	183.4	232000

Table 1: Industrial fishery data for the aggregated sole catch, effort and reported landings. Note that reported landings do not always agree with the actual catch data in the paper record. Highlighted cells were estimated by extrapolation or substitution. See Figure 4 also.

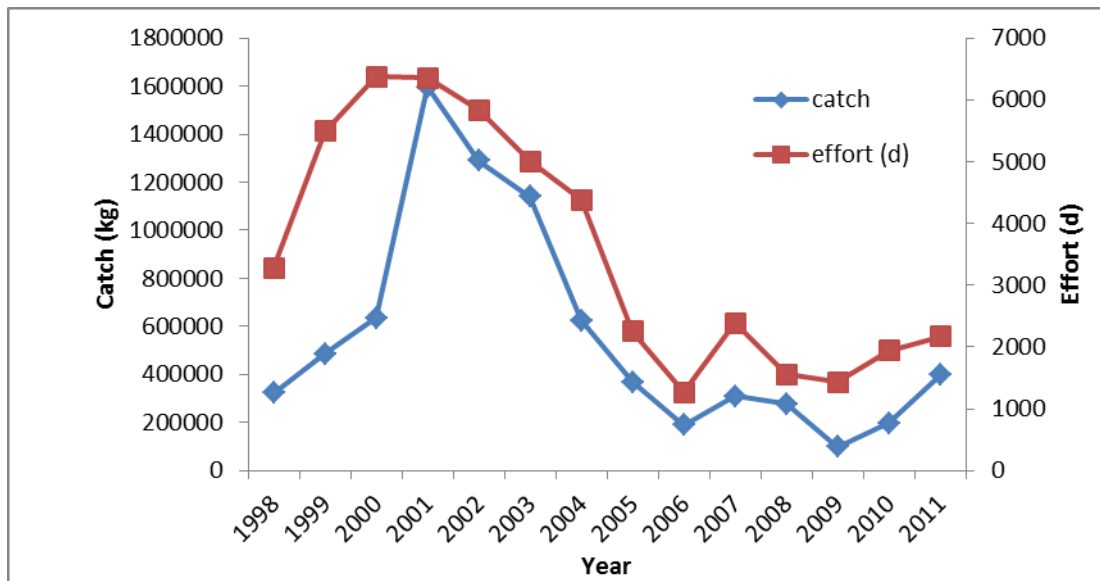Figure 3: Time series of industrial sole catch (kg) and effort (days fishing). Note that as effort increases catch increases almost linearly.
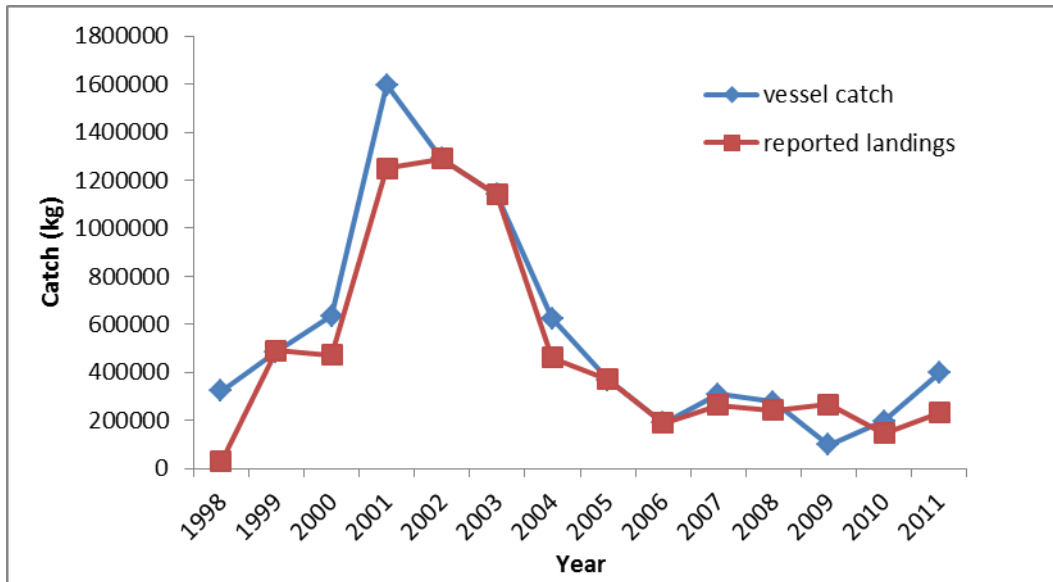
Figure 4: Time series of summed industrial vessel catch data for sole as reported to DOFish by radio, and the published or reported industrial catch data.
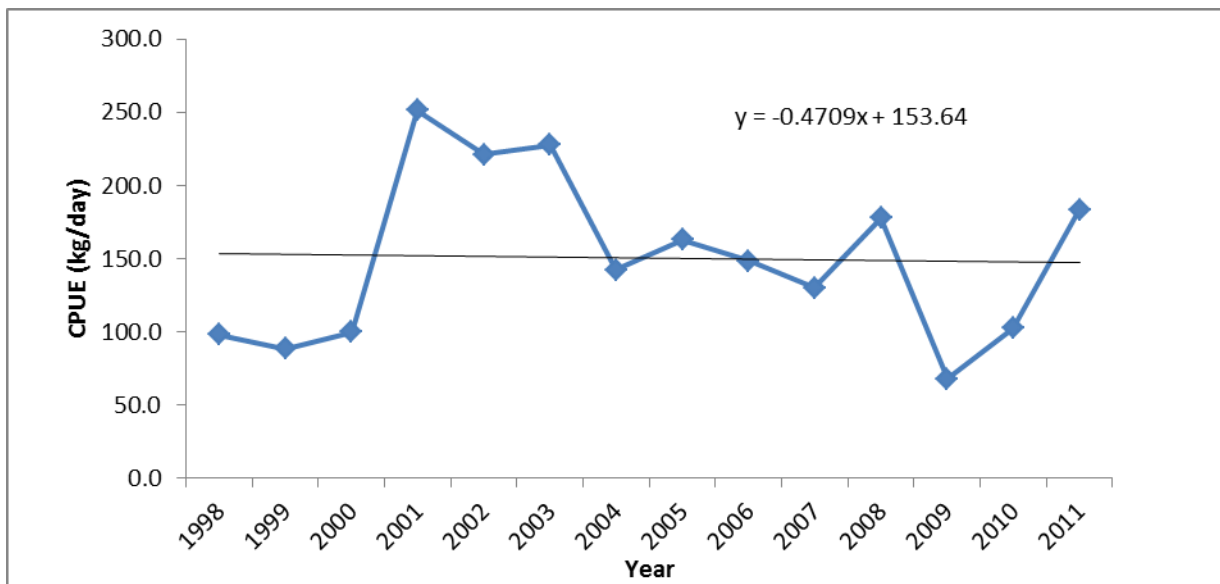

Figure 5: Mean annual CPUE (kg/day) for sole fish based on industrial fishery dependent trawling in Gambian waters.

ESTIMATION OF THE LEVEL OF EXPLOITATION AS COMPARED TO REFERENCE POINTS

Introduction

Medley et al. (2008) conducted an assessment of the level of exploitation of sole in Gambian waters based on catch curve analysis from data obtained from Atlantic Seafood, and compared that to reference points estimated from a SSBPR analysis. That analysis, as part of a sustainability pre-assessment (MSC Sustainable Fisheries Certification Report, 2008), was based on the weight distribution of landings processed by the company during the period 2006-2008 (Table 2).

Wt. Cat. (g)	Mean Wt (g)	Mean Lt. (cm)	Mean Age	Total Wt. (kg)	Estimated No.	Wt. Proportion
100/200	169	30.1	2.0	166554	985527	0.18
200/300	250	34.6	2.5	348974	1395898	0.38
300/400	350	39.2	3.1	244194	697698	0.27
400/600	500	44.6	4.0	103364	206728	0.11
600/700	650	49.0	5.0	39327	60503	0.04
700/1000	850	54.0	6.8	8250	9706	0.01

Table 2: The summarized weight distribution of red sole processed by Atlantic Seafood in the 2006-2008 period.

The results of the Length-Based Catch Curve Analysis (LCCA) of this red sole processing data indicated that the slope of the linear regression of Ln (catch) versus the age was 1.124, or total mortality was 1.12, therefore, F was estimated to be 0.49. This analysis was based on the following input parameters for the life history characteristics: Linf=60 cm, K=0.34, and M=0.72. Based on this LCCA, the red sole stock was determined to be not over-exploited, as the estimated F was less than the F 40% from the SSBPR analysis. Medley et al. (2008) also noted that the total proportion of two smallest weight categories (100-200, 200-300g) is 0.56, and the proportion of large fish >300g is 0.46. From these proportions they concluded that the proportion of large fish in the population is consistent with a fish stock that is not over-fished.

In the 2006-2008 period landings of sole reported by the Gambia Department of Fisheries were between 1107 and 1559 mt (Table 3).

Year	Art. Catch (mt)	Ind. Catch (mt)	Total Catch (mt)
2006	1371	188	1559
2007	1293	264	1557
2008	865	242	1107

Table 3: Landing of mixed sole fish on 2006-2008 as reported by the Gambia Department of Fishereis.

The purpose of this section of this report is to present the results of a similar analysis to that conducted by Medley et al. in 2008, but on more comprehensive data collected in 2010. The goal of this new analysis is the compare the estimated level of exploitation of sole fish in 2010 to management reference points.

Methods

The analyses included in this report were conducted in May 2012, but were based on data collected in 2010-2011 by the BaNafaa project at the artisanal landing sites and by Atlantic Seafood in its processing plant in Banjul, the Gambia.

Length-based Catch Curve Analysis was conducted on length frequency distributions collected at the beach landing sites in second half of 2010 and first half of 2011. These data were collected based on random samples of the catch, and measurements were made at 0.5 cm intervals and by month. Data were collected on the two dominant species landed: red sole (*Cynoglossus senegalensis)* and black sole (*Synaptura cadenati)*. These data were expanded and resorted at 2.5 cm interval, and finally summed for the 12 months. The lengths of the mean of the fish length categories were converted to mean age using a von Bertalanffy growth equation using specific value of Linf and K, the growth coefficient. To determine the total mortality, the natural log of the numbers captured was plotted versus the estimated age at mean length, where the slope of the linear regression trend line is the total mortality. The regression slope was estimated on fish that were fully recruited to the fishery as indicated by steadily decreasing numbers in the catch. Fishing mortality was estimated by subtracting an estimate of natural mortality from total mortality.

Yield per recruit (YPR) and spawning stock biomass per recruit (SSBPR) analyses were conducted to estimate growth and recruitment overfishing reference points for sole fish. These analyses were conducted using a method described by Haddon (2001), using life history parameters that were estimated from the best available information, including age and growth analyses conducted as part of the BaNafaa project (Gabis, et al, 2011b). The very limited age and length data presented in that report based on otoliths

were re-analyzed using alternative methods and omitting limited or outlying data points with limited observations to produce a range of maximum lengths (L_∞) and growth coefficients (K).

Catch data for the artisanal and industrial fisheries were taken from published data provided by the Gambia Department of Fisheries. Data on the weight distribution of fish processed in 2010 were provided by Atlantic Seafood in Banjul.

Results

The length-frequency distributions of red and black sole measured at the landing sites were transformed into natural log of catch numbers versus age for the 2010-2011 catch data (Figures 6 and 7). More than 33,000 red sole and about 14,000 black sole were sampled and measured in the Banafa project. Note that the slope of the trend line depends on the assumed values of the growth function (Linf and K), that were used to convert the mean category length to an age. The series are divided into two sections those fish not fully recruited to the fishery, and those fish fully recruited to the fishery. The slope to the trend line of the natural log of the catch numbers versus the mean age is the total mortality.
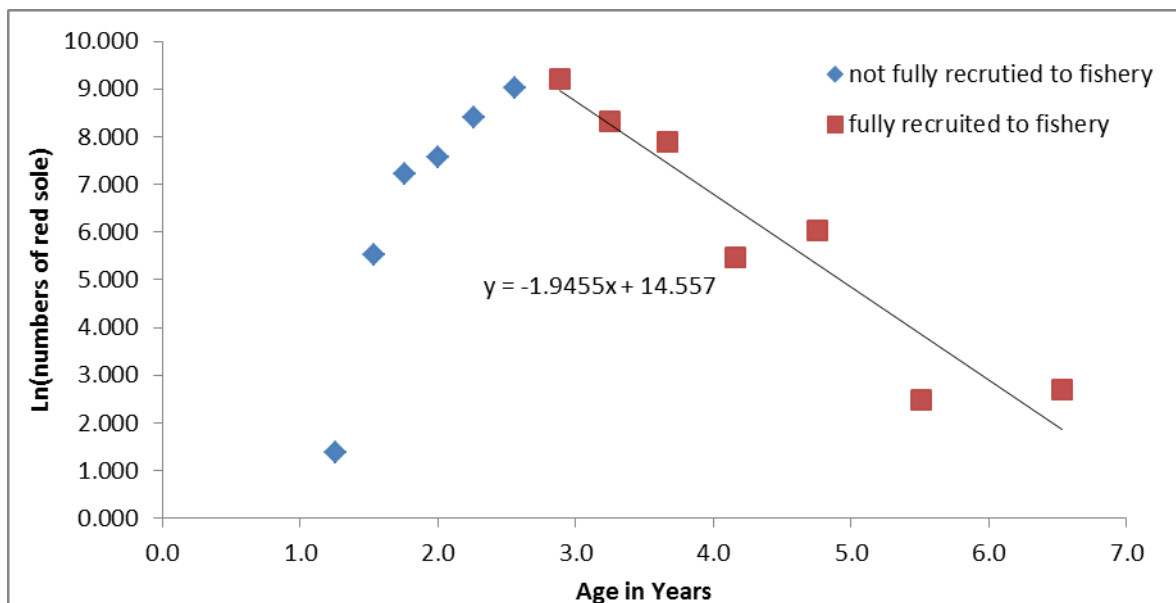

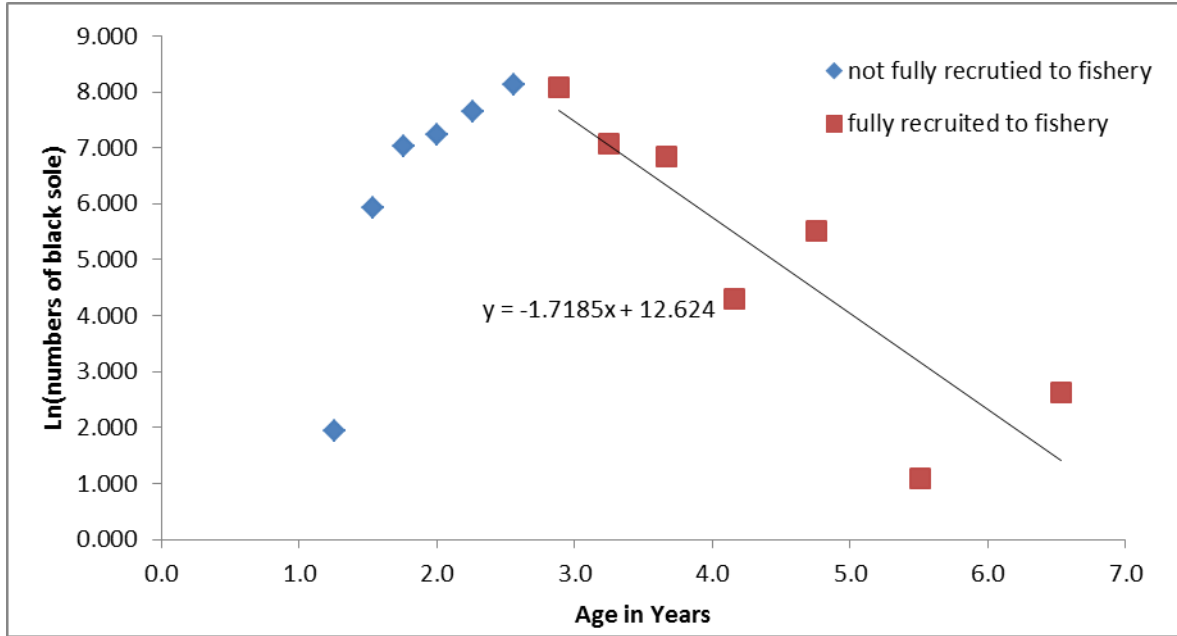Figure 6: Results of LCCA for red sole.

Figure 7: Results of LCCA for black sole

A sensitivity analysis was conducted to determine the effect on the assumed values of Linf, K, and M on the resulting estimate of fishing mortality, F (Tables 4 and 5). The re-analysis of the Gabis et al (2011) data results in a range of values for L_∞ of 40-51 cm , and K of 0.2-0.7. Recall the Medley et al. analysis in 2008 used values of 60, 0.34 and 0.7 for L_∞ , K and M, respectively. In this study natural mortality was estimated to possibly range from 0.4 to 0.6, and the age and growth study found a 5 year old black sole that was only 38 cm in length. Given that some sole are landed that exceed 50 cm in length, this suggests that sole are longer lived than assumed by Medley et al. (2008), and therefore M must be less than 0.7.

Linf=	65.0	65.0	60.0	60.0	57.0	55.0	55.0	55.0	53.0
K=	0.40	0.35	0.40	0.35	0.35	0.35	0.35	0.30	0.30
M=	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6
Z=	3.9	3.4	2.9	2.5	2.0	1.6	1.6	1.3	0.9
F=	3.5	3.0	2.4	2.0	1.5	1.1	1.0	0.7	0.3

Risk Adverse   Best   Risk Prone

Table 4: Red sole LCCA sensitivity analysis

Linf=	65.0	65.0	60.0	60.0	57.0	55.0	55.0	55.0	53.0
K=	0.40	0.35	0.40	0.35	0.35	0.35	0.35	0.30	0.30
M=	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6
Z=	3.4	3.0	2.5	2.1	1.7	1.4	1.4	1.2	0.8
F=	3.0	2.6	2.0	1.7	1.2	0.9	0.8	0.6	0.2
	Risk Adverse					Best			Risk Prone

Table 5: Black sole LCCA sensitivity analysis

The results of the LCCA analysis suggests that the best estimate of fishing mortality (F) for red and black sole is 1.5 and 1.2, respectively, based on L_∞ , K and M values of 57 cm, 0.35 and 0.5, for both species. The slope of the fully recruited numbers versus age was also re-calculated using an additional data point that included a slightly younger age, but this only changed the slope less that 0.1 units of total mortality, and therefore did not substantively change the outcome of the analysis.

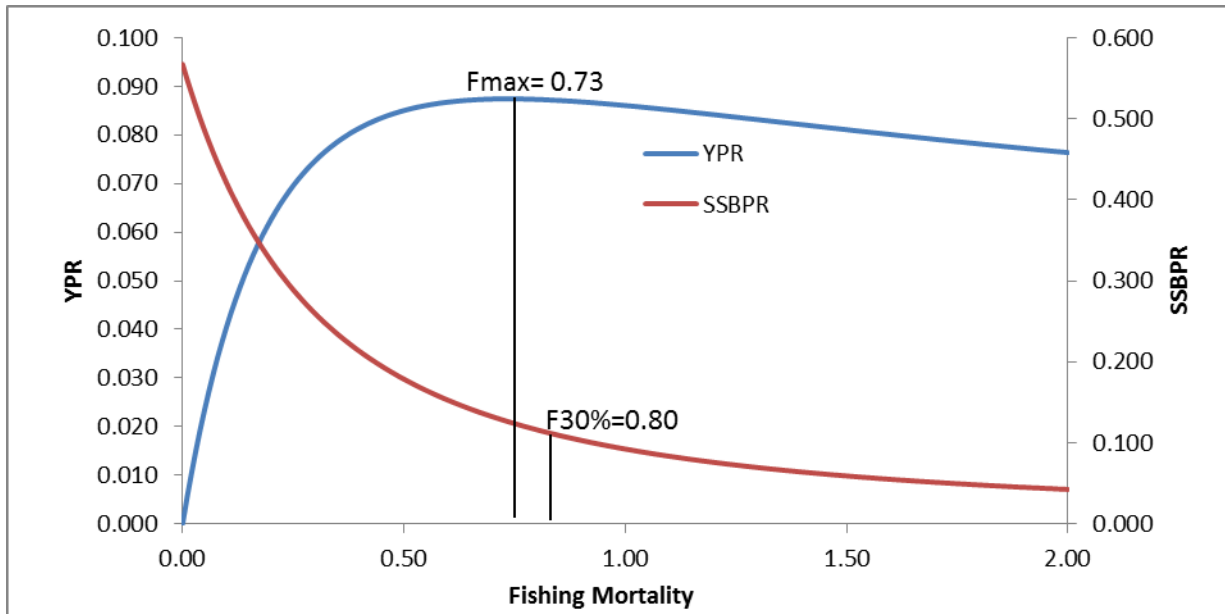The results of the YPR and SSBPR analyses for red and black sole are summarized in Figure 7.

Figure 8: Results of YPR and SSBPR analysis for red and black sole.

The reference points for growth and recruitment overfishing, Fmax and F30%, for red and black sole are 0.73 and 0.80, respectively.

Comparing the results of the LCCA to the reference points estimated in the YPR and SSBPR analysis, both red sole and black sole were experiencing growth and recruitment overfishing in 2010-2011.

The catch data for 2010 and 2011 from the Gambia Department of Fisheries ranged for 1085 to 2219 mt (Table 6).

Year	Art. Catch (mt)	Ind. Catch (mt)	Total Catch (mt)
2010	938	147	1085
2011	1987	232	2219

Table 6: Landings of aggregated sole fish as reported by the Gambia Department of Fisheries.

Note that the catch of sole fish appears to increase dramatically in 2011, suggesting overfishing.

Finally, the weight distributions of red and black sole processed by Atlantic Seafood in 2010 are shown in Table 7. Note that it appears that Atlantic Seafood processed about 50% of the sole fish landed in the artisanal fishery in 2010.

	Red Sole		Black sole	
Wt. Cat.	Total Wt.	Proportion	Total Wt.	Proportion
100-200	153931	0.41	85494	0.53
200-300	193349	0.51	55122	0.34
300+	32629	0.08	21677	0.13
Total	378909		162294	

Table 7: Weight distribution of red and black sole processed in 2010 at Atlantic Seafood.

These data indicate that the proportion of larger fish (>300 g) in the population is relatively small in 2010, 8% for red sole and 13% for black sole, as compared to 2006-2008, based on the data used by Medley et al. in his 2008 analysis.

Additional data on weight distributions of red and black sole was for 2011 and 2012 was requested from Atlantic Seafood, but the data was both incomplete for 2011 and 2012,

as sole fish were being processed without regard to weight categories in many months of the year, and the few months where the fish were properly sorted, the data for the total fish processed was only a small portion of the total sole processed for that month, and therefore could not be consider as representative.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Current landings of sole fish in the Gambia by the artisanal fishery are about 1500 mt annually and in the industrial fishery are about 200 mt annually. By comparison current landings of sole fish in Senegal are reported to be substantially greater. If the stock is a shared single stock then a joint assessment is preferable to just The Gambia alone. However, information from the local knowledge sessions indicated that sole seasonally move both from the north and the south to the Gambian waters (Drammeh et al., 2011), suggesting that there could be separate management units.

The mean CPUE for the artisanal fishery is about 50 kg per day of fishing, while the more efficient industrial fishery has a mean sole fish bycatch CPUE of about 150 kg per day of fishing. Neither index has a trend that is significantly different from zero, suggesting that either the indices are not representative of relative stock abundance or that the relative stock abundance of the sole stocks has remained unchanged in the last decade. While the CPUE values appear to be representative, the lack of a significant negative trend is puzzling in light of the other analyses.

The results of the LCCA and reference point analyses presented in this report suggest that red and black sole are now over-exploited, as the estimated level of fishing mortality is greater than both the growth and recruitment overfishing reference points. This is also confirmed by the lack of larger fish in the population, only 8-13% in 2010 as compared to 46% on 2006-2008. The overall catches of sole in 2010 do not appear to be excessive as compared to the 2006-2008 period, but the catches in 2011 appear to be high.

In conclusion, the data available for analysis do not allow for an estimate of stock size for either red sole, black sole, or for the species complex, or the estimation of the biomass level at maximum sustainable yield (B_{MSY}). But given the excellent data on the size distribution of fish landed in 2010 and 2011 in the artisanal fishery, and the analysis of this data using LCCA, it is clear that the sole fish stock in the Gambia is over-exploited. This is confirmed by the lack of large fish (>300 g) in the processed fish data form Atlantic Seafood in 2010 as compared to 2006-2008. However it must be noted that this conclusion is must be reconciled with the lack of a significant negative trend in the CPUE indices for the artisanal and industrial fisheries. While this is puzzling, it is more than likely due to the limited data that used to estimate the CPUE indices. This results in uncertainty in these CPUE indices that has not been quantified.

Based on these results, the following recommendations are made: The sole fish stock must be defined by species and spatial extent. Then data on landings and effort for the

stocks must be collected. For the management unit that includes the sole fish in the Gambia, it is clear that fishing mortality must be reduced, so as to allow the fish to grow to a larger size. This will increase the spawning biomass, and eventually increase the stock abundance. To reduce fishing mortality, fishing effort must be reduced, and this can be achieved through limiting new entrants into the fishery, and limiting the days of fishing allowed through closed seasons or reduced fishing weeks. Additional investigations of the growth and maturity of sole fish are required so as to provide less uncertainty in these life history parameters.

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