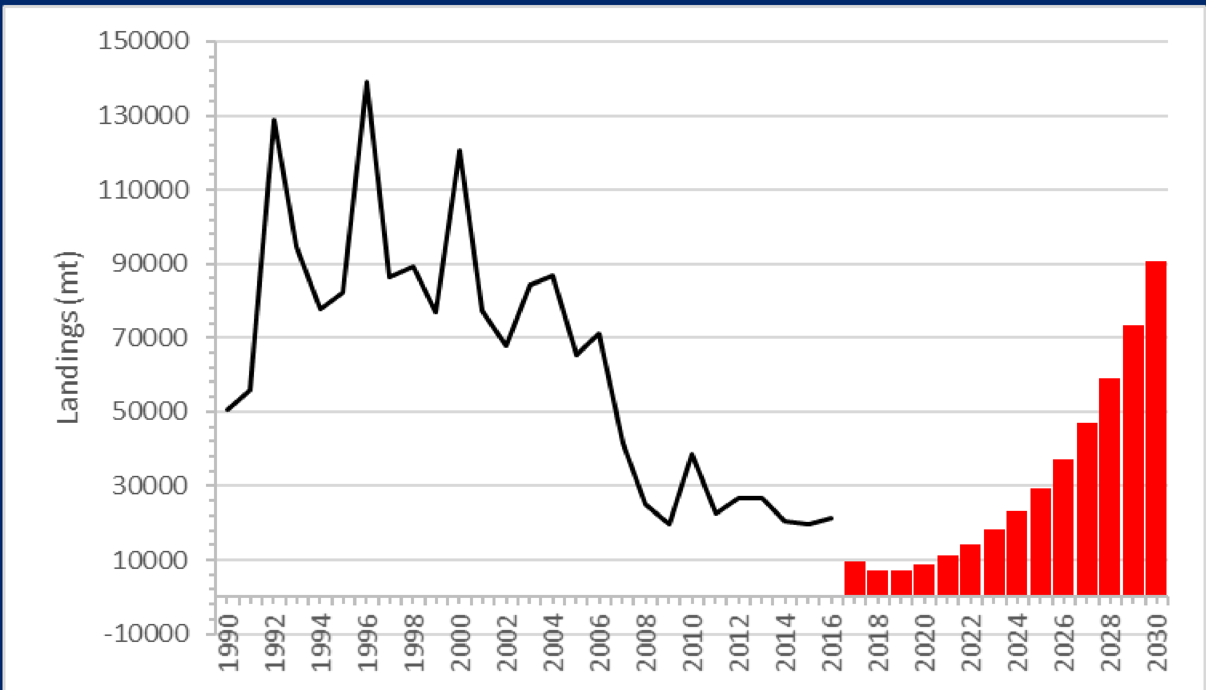
SUSTAINABLE FISHERIES MANAGEMENT PROJECT (SFMP)

Status of Ghana's small pelagic stocks and recommendations to achieve sustainable fishing 2017



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Cover photo: Scenario for rebuilding fish stocks (see Figure 9 Changes in annual landings under a F=0.4 scenario)

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ACRONYMS

CCM	Centre for Coastal Management
CECAF	Fishery Committee for the Eastern Central Atlantic
CPUE	Catch Per Unit Effort
EEZ	Exclusive Economic Zone
FAO	United Nations Food and Agriculture Organization
FC	Fisheries Commission
FSSD	Fisheries Scientific and Survey Division
ICCAT	International Commission for the Conservation of Atlantic Tunas
MOFAD	Ministry of Fisheries and Aquaculture Development
MSY	Maximum Sustainable Yield
SFMP	Sustainable Fisheries Management Project
STWG	Scientific and Technical Working Group

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INTRODUCTION

This report provides an update of the status of the small pelagic fish stocks in Ghana through 2017. It was led by the Scientific and Technical Working Group (STWG) of the USAID/ Sustainable Fisheries Management Project (SFMP). The information contained here was obtained from the Fisheries Scientific and Survey Division (FSSD) of the Fisheries Commission (FC) of Ghana and other available information.

In this report we use the best available scientific information to show the status of small pelagic stocks in Ghana. Although these stocks extend beyond the borders of Ghana's EEZ, we assume, for management purposes only, that the landings from Ghana form single small pelagic stock. While we recognize that this assumption may not be valid but since the landings realized in the EEZ of Ghana represent a large share of the Gulf of Guinea, it is fair to assume that that this assessment is indicative of the rest of the stock outside the boundaries of Ghana.

Previous assessments established the biological reference points (management indicators), for which could maintain sustainability of the stocks. The management indicators were computed and validated by the STWG in 2015 in the initial stock assessment (See Lazar, Yankson, Blay, Ofori-Danson, Markwei, Agboga, Bannerman, Sotor, Yamoa, Bilisini, 2016).

The small pelagic resources, particularly sardinella, are on the verge of collapse. Annual landings have been in decline for more than a decade as fishing effort has increased (Figure 1). This drastic decline in landings is due primarily to overfishing and overcapacity of the fishing fleet. Fishing pressure is driven largely by the artisanal fleet operating under open access rules using bigger and more efficient fishing gear and technologies. The average purse seine size is about 800 m today as opposed to 275 m in the 1970s. Canoes' gross tonnage and capacity increased by 2.5 fold (from 2 to 5 tons). The CPUE declined and the cost of a fishing trip increased due to additional expenses for longer trips.

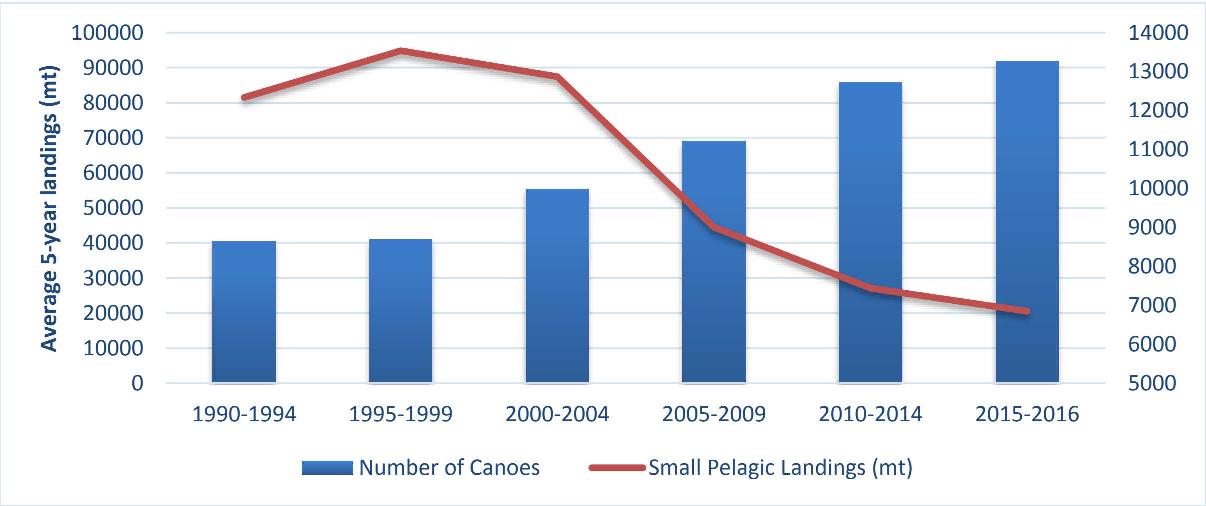

Figure 1. Landings of small pelagic stocks (Sardinellas, Anchovies and Mackerel) in orange and effort in number of canoes targeting small pelagics from 1990 to 2016 in Ghana.

The 2015 stock assessments were performed using a surplus production model employing non-equilibrium and dynamic approaches (see Lazar *et al*., 2016), in which the effort data series were not calibrated and measured by direct observations of the number of purse seine canoes. The CPUE derived from this effort is supposed to reflect the true abundance of fish at sea. However, the inability to measure changes in catchability (lack of measuring the changes in efficiency over time) create a significant bias with regards to abundance. In this report we continue to provide a new approach to model configuration by calibrating the effort using information obtained from a semi-structured field survey conducted by Hen Mpoano in 2015. The survey used the local knowledge of experienced fishermen to reconstruct the historical perspectives relative to fishing units (size of the canoe, size of the net, crew size, outboard motor HP, and other factors). (Asare *et al*., 2016).

SMALL PELAGIC FISH STOCKS

The small pelagic fish stocks are composed of round sardinella (*Sardinella aurita),* flat sardinella *Sardinella maderensis,* anchovies (*Engraulis encrasicolus) and* mackerel (*Scomber colias).* The four species represent more than 80% of the total small pelagic fish stocks in Ghana. They have common biological and ecological traits and are exploited in large by an artisanal fishery using purse seines, encircling gillnets and beach seines. The catch of small pelagics is processed for local consumption, either smoked or dried. The biological and ecological profile of these species were described in Lazar *et al.,* 2016.

STOCK UNIT DEFINITION

Accurate fish stock identification of small pelagic stocks in Ghana is currently absent. The monitoring of the status of the small pelagic stocks is determined by the regional working group of the Committee for the Eastern Central Atlantic Fisheries (CECAF) of the Food and Agriculture Organization (FAO). Sardinellas caught in the southern CECAF area from Guinea to Angola are composed of two species, round sardinella (*Sardinella aurita*) and flat sardinella (*Sardinella maderensis*). Research surveys carried out in the CECAF area show that the two species are found in a vast area stretching from the Mediterranean to Namibia. However, for management purposes and in the absence of information on stock identification, the FAO/CECAF Working Group has agreed on the existence of four stocks for these two species in the southern CECAF area. Northern zone (Guinea-Bissau, Guinea, Sierra Leone and Liberia), western zone (Côte d'Ivoire, Togo, Ghana, and Benin), central zone (Nigeria and Cameroon) and southern zone (Gabon, the Democratic Republic of the Congo, the Congo and Angola) areas (Figure 2). This is an assumption based

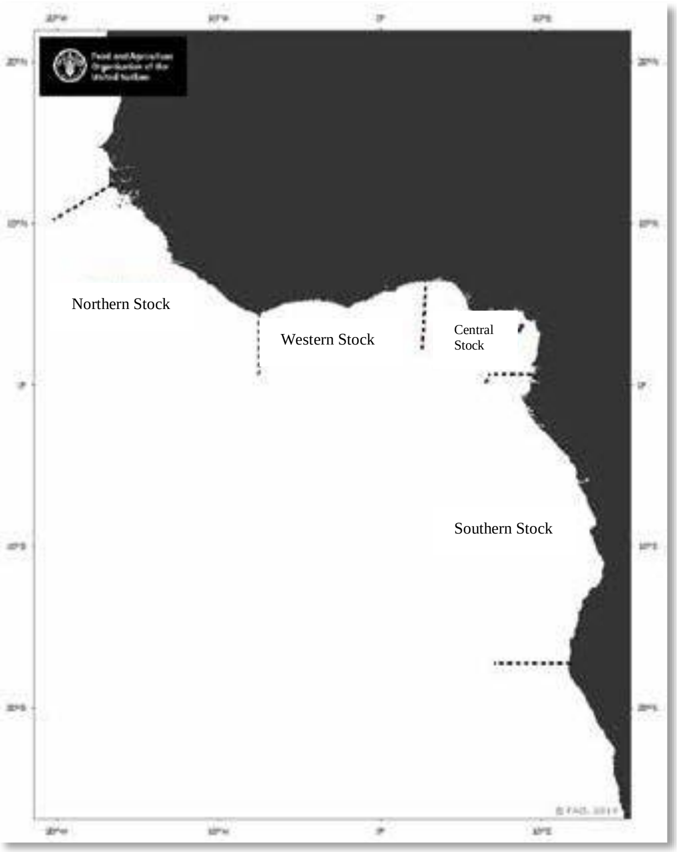

Figure 2 Spatial stock identification of sardinella in the south CECAF area

on management needs and in the absence of information to match the biological boundaries of these two species with management strategies.

The SFMP is collaborating with the Fisheries Committee for the West Central Gulf of Guinea (FCWC) and CECAF to describe the genetic stock structure of round sardinella (*S. aurita*) and flat sardinella (*S maderensis*) in the CECAF region (Morocco – Angola). This research is underway at the University of Rhode Island's College of Environment and Life Sciences as part of a MS thesis of a Ghanaian student from the University of Cape Coast. Results are expected to be released in June 2018.

DATA SOURCES

Landings and effort

The artisanal purse seine, encircling gillnets and beach seines are the main fishing gear used for the exploitation of small pelagics. There are two types of artisanal purse seine gear, and the difference is in the mesh size. The purse seine with a 25 mm mesh is locally called "*watsa*," while the one with a 10mm mesh is called "*poli*". The beach seine has a mesh size of 10 mm and is common in Volta and Western Region, mainly along estuaries. Purse seines are operated from canoes ranging between 10 to 20 meters. There are over 3000 artisanal purse seine canoes and 900 beach seine canoes operating along the entire coast.

Total landings have been in sharp decline since 2000, reaching their lowest level in 2016 at 19,608 tonnes (Figure 3). This represents 14% of the highest landings recorded in 1996 of 138,955 tonnes. The average zero catch (vessel spending more than 20 hours searching for fish and returning to port/landings site with no catch) has increased. Fishermen reported that in 2017, more than 25% of vessels in Tema returned to harbor without catch (Personal communication).

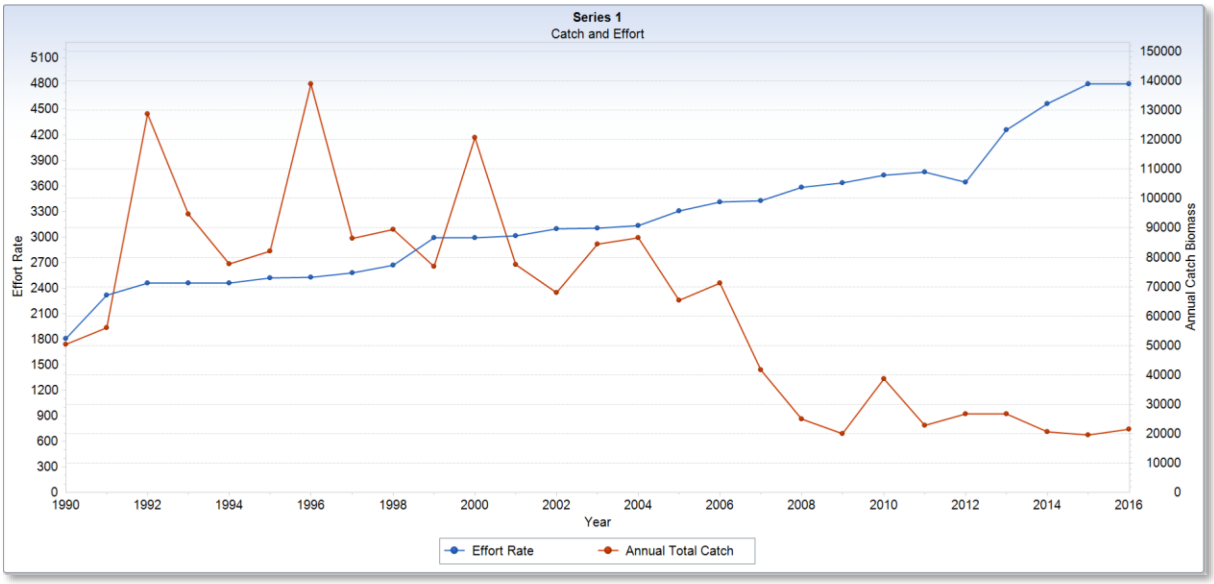

Figure 3 Total landings of small pelagic stocks (Sardinellas, Anchovies and Mackerel) in red and effort in number of canoes targeting small pelagics from 1990 to 2016 in Ghana.

The rapid decline of small pelagic landings suggests that biomass has declined as a result of overfishing. This is corroborated by a noticeable decline in CPUEs and by the presence of small fish sizes in the catch recorded in almost every landing site due to the use of smaller mesh sizes (less than 5 mm). The lack of fish in nearshore areas has transformed the operations of the artisanal fisheries using bigger nets, large number of fishermen onboard bigger canoes. This change in the fishery affected the associated catch rates (landings/trip) which are no longer comparable to the early years. A calibration of the unit of effort throughout the time series is therefore necessary to make a standard index of abundance based on fisheries dependent information.

For this assessment, we measure fishing effort in number of canoes targeting small pelagics for more than half of the year. This information was obtained from FSSD and from the frame survey data (1990-2016). We included the number of purse seine canoes recorded during the 2016 frame survey (Dovlo, Amador, Nkrumah, 2016). In order to calibrate the unit of fishing effort, we relied on the results of a field survey conducted by SFMP in 2015 used to standardize the fishing effort in KW-units using fishermen's historical knowledge (Table 1).

Table 1. Results of the interviews with fishermen for CPUE calibration for small pelagics in Ghana

	1970-1980	1980-1990	1990-2000	Present
TOTAL LOA – Canoe (meters)	10	13	15	22
HP	15	25	40	55
KW (HP/1.34)	11	19	30	41
VCU(Vessel Capacity Unit) = (LOA*BR)+045*kw	50	109	201	406
Crew-carrying unit	10	12	15	25
Net-length (m)	275	500	550	800
Net-depth (m)	30	25	25	55
mesh size (cm)	2.5	2.5	1	0.5
Carrying capacity (mt)	23	29.9	34.5	50.6
CPUE (# of boxes=30 kgs/canoe)	50	40	30	10
Days at sea per trip	1	1	1	1
Power of the canoe (LOA*KW)/1000	4.72	5.49	6.1	6.81
Power of the seine (L*D*Crew size)/1000	11	12	12	14
Total Unit power	53.41	65.45	74.7	94.67
Percent Change (70-80 as reference)	0	18.39	32.53	55.24
Percent change (1980 as reference)		0	12	39

Stock Assessment Model

A surplus production model was fit to observed landings and effort data of small pelagics (sardinellas, anchovies and mackerel). The landings of the three major small pelagic species represent an indicator for the status of all small pelagic species, in the absence of reliable abundance data (CPUE and acoustic surveys). Fishing effort is represented by the number of purse seine canoes calibrated to account for the changes in the efficiency of a fishing trip. We didn't use the auxiliary estimates of abundance using acoustic surveys. The model is a mass balance approach in which stock biomass each year is the biomass the year before plus new production minus the catch removed. New production is the net difference between additions from growth and recruitment and mortality losses.

The stock growth is assumed to follow the familiar logistic curve.

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t + \epsilon$$

Where:

t = year

B_{t+1} = population biomass of next year

(t+1)

B_t = population biomass of this year (t)

r = intrinsic rate of increase in biomass

ϵ = lognormal process error

The (*r*) parameter is a measure of population growth rate at very low abundance when density dependent factors are inoperative. The term in parentheses is the density dependent feedback mechanism that reduces stock growth when abundance is high.

The average catch rates (CPUE) is expressed as the product of biomass (*B*) and the catchability coefficient (proportion of the total stock taken by one unit of effort) represented by (*q*). The relationship between the catchability q and the CPUE is:

$$\overline{CPUE} = \frac{Catch}{Effort} = qB$$

Where:

q = catchability coefficient

CPUE = Catch-Per-Unit of Effort

B = Biomass

The model is then fit iteratively by minimizing the sum of square residuals between observed CPUE and predicted CPUE in the form of:

$$\sum (CPUE - \overline{CPUE})^2$$

Where *CPUE*, representing an Index of abundance (I), is the observed rate from which to subtract the predicted or expected *CPUE* from the model.

The management quantities for sustainable fisheries can be derived from the logistic model parameters as follows:

$$MSY = \frac{rK}{4}$$

$$F_{msy} = \frac{r}{2}$$

$$B_{msy} = \frac{K}{2}$$

Maximum sustainable yield (MSY) is the maximum yield that a stock can deliver year after year over the long term. It is a function of both carrying capacity and stock productivity. In order to produce MSY, a stock needs to be at a biomass level equal to one-half carrying capacity (B_{msy}) and be subject to a fishery removal rate no greater than F_{msy}. The latter is equal to one-half the maximum rate of stock growth. A fishing mortality rate that approaches the maximum rate of stock growth will lead to stock collapse (F_{coll}).

Fishing Effort Calibration

The abundance indices CPUE were calibrated based on fishermen's knowledge, using the information from the survey conducted by SFMP on historical trends of fishing capacity and gear efficiency. The CPUE were corrected using the results of the survey summarized in Table 1 as follows:

$$CPUE_{corrected(i)} = \frac{CPUE_{observed\ (i)}}{(1+\alpha)^{i-i_o}}$$

Where $CPUE_{observed(i)}$ is the raw number of canoes targeting small pelagics estimated by the frame surveys over the period from 1990-2016; $CPUE_{corrected(i)}$ is the corrected index for the period of years i, and α is the annual rate of increase of fishing power of the artisanal canoe fishery.

The increase in efficiency is linked to modernization of the canoes, increased horsepower of outboard engines, and increase in net size. The use of light fishing is another factor improving efficiency, however the FSSD report of 2005 demonstrated no evidence of the use of light fishing (Bannerman, 2005). Fishermen believe that light fishing is a significant tool for increased fishing efficiency and success. A study to better measure claims of increased efficiency resulting from light fishing could be useful and might result in a revised calibration to improve the fit of the surplus model (Lazar, *et al.* 2017).

RESULTS

The model performed well and provided a reasonable level of precision (CV=0.36) relative to the estimates of biomass, intrinsic rate of increase and catchability. Estimated biomass of total small pelagic species in Ghana declined sharply following the trends of landings. Recent levels have reached the lowest point over the period between 1990 and 2016. Biomass in 2016 was estimated at 27,680 tonnes (Figure 4). This represents about 8.4% of the biomass needed to maintain sustainable exploitation of the stock. The rebuilding target B_{msy} was estimated at 315,200 tonnes. The terminal relative biomass (B_{2016}), expressed in a ratio of current biomass divided by B_{msy} was estimated at 0.084.

Small pelagic fish stocks in Ghana are considered overfished. Fishing mortality has gradually increased in the past 25 years reaching high and unsustainable levels in 2016. The fishing mortality in 2016 was estimated at F=0.88 (Figure 5). The recent Fridjoft Nansen research acoustic survey conducted in September 2017 in the waters of Ghana estimated similar levels of biomass for small pelagic stocks, noting a possible collapse of the sardinella stocks (personal communication).

For small pelagic fish stocks, we select two types of biological reference points (biological indicators) measuring fishing mortality (F) and biomass (B). The two indicators are Fmsy (sustainable level of harvest rate) and B_{msy} (sustainable biomass level for which the stock can continue to produce a maximum yield without jeopardizing the stock known as MSY).

F_{msy} is the level of harvest needed to achieve sustainability in the long term based on growth and reproductive rates. The F_{msy} for the small pelagic stocks is estimated by this model at Fmsy=0.3, compared to the F_{msy}= 0.4 estimated using the same production model with non-calibrated effort. The STWG decided to maintain the original reference points for fish stock performance, as it is consistent with estimates applied in fisheries management of small pelagics.

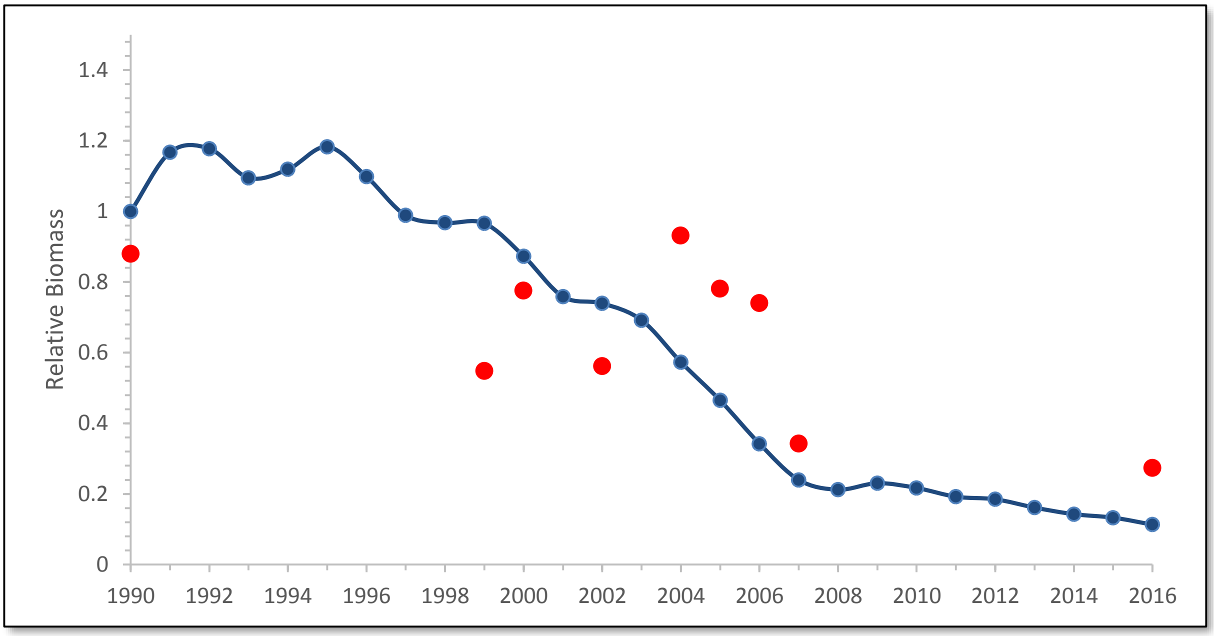

Figure 4 Model estimates of relative biomass trends of small pelagic fish stocks (blue line) and acoustic survey point estimates (red dots) from the acoustic surveys from R/V Fridtjof Nansen (1990-2016).

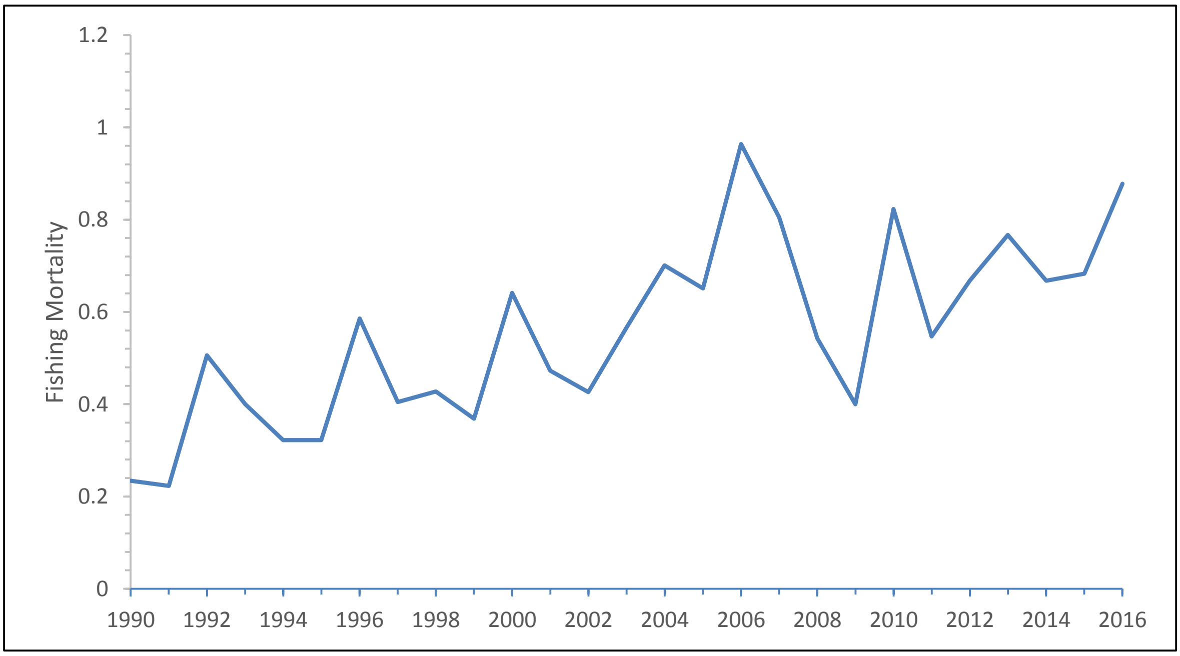

Figure 5 Trends of fishing mortality of small pelagic stocks (Sardinella, Anchovies and Mackerel) from 1990 to 2016 in Ghana.

We note no significant changes in B_{msy}, Therefore the rebuilding target of small pelagic stocks remains at 315,200 tonnes.

The comparison between 2015 and 2016 (Table 2) indicates an increase in fishing mortality and a severe decline in population size. The estimates of biomass in 2015 were based on the time series of CPUEs calibrated to account for increased efficiency. This type of fine-tuning of the abundance index ($B_{current}$) resulted in an estimated biomass much lower in 2015 than those estimated in 2014 Table 2). This is due to model specifications, as CPUE is directly correlated to catchability (efficiency).

Table 2 Model estimates of current biomass, fishing mortality rates and management reference points.

Biological reference points	2014	2015	2016
B_{msy}	310,476 tonnes	310,000 tonnes	315,200 tonnes
F_{msy}	0.40	0.30	0.30
$B_{current}$	32,910 tonnes	30,000 tonnes	21,750 tonnes
$F_{current}$	0.74	0.80	0.88

The STWG concludes that current fishing effort is well beyond the level of sustainability for the small pelagic stocks. In the absence of effort control measures, stocks will continue to decline with diminishing economic returns, leading to further deterioration of social conditions in fishing communities.

It is common for small pelagic species (forage species) to be more prone to rapid collapse than other types of marine fishes due in part to their rank in the food web and their response to environmental conditions. These fish occupy a very special position in food webs, ensuring energy transfer between species at lower and higher levels, while forming a narrow range of species richness. The collapse of the pelagic stocks therefore, have a domino effect on both higher and lower trophic species.

We use a traffic light color convention to illustrate the history of overfishing (fishing mortality and biomass) in Figure 6. Employing a precautionary approach, the ratio of F/Fmax and B/Bmax should be in the green box, placing fishing mortality slightly below the target reference point and biomass slightly above the target reference point. In this box the fishery is not overfished and overfishing is also not occurring. The orange box is an area where fishing mortality exceeds the target but biomass is still above the target. Overfishing is occurring but the stock is not yet overfished. The red box is the worse place to be, where fishing effort exceeds the target (F/Fmax>1) and biomass is also below target (B/Bmax<1). This means that overfishing is occurring and the stock is also overfished. The yellow box is where fishing mortality is below the target but biomass is also still below target. This typically shows the period of rebuilding a fishery where fishing mortality is reduced below the F/Fmax ratio = 1, but where the B/Bmax ratio is less than 1, and the stock is still considered overfished even though overfishing is no longer occurring. Then over time, the Biomass can be rebuilt to B/Bmax equal to or greater than 1 (green box). At this point the fishery will be considered rebuilt and able to produce sustained maximum yields.

In the early 1990s the small pelagic fishery in Ghana was not overfished and overfishing was not occurring (green box). However, in the in the late 1990s and early 2000s effort increased and fishing mortalities exceeded levels to maintain MSY even though the stock was not yet overfished (orange box). However, the overfishing resulted in the stocks being depleted, so that by the mid-2000s to the present time, continued overfishing resulted in the stock also becoming overfished, and a significant drop in annual landings is associated with this period (see Figure 1) resulting in the depleted levels of annual catch seen over the past several years. In 2016, the graphic shows that biomass is at historic lows and fishing morality almost at historic highs.

The historical trends shown by the traffic light color convention (Figure 6) of small pelagics fishery suggests that the existing fisheries governance have failed totally. The current regulatory system and its inability to properly manage these resources may not be sufficient to provide a road map for a recovery plan. However, in the United States and in the EU, when a fishery is depicted as overfished and overfishing continues to occur within three consecutive years (in a red box) the fishery is totally shut down to allow the stock to rebuilt its biomass to the level that is capable to produce MSY. The 10-year time frame creates discrepancies in rebuilding approaches for short versus long-lived species and for lightly depleted versus heavily depleted stocks. These discrepancies are considered by some to be arbitrary or unfair, however they served well for rebuilding depleted fish stocks in the United States.

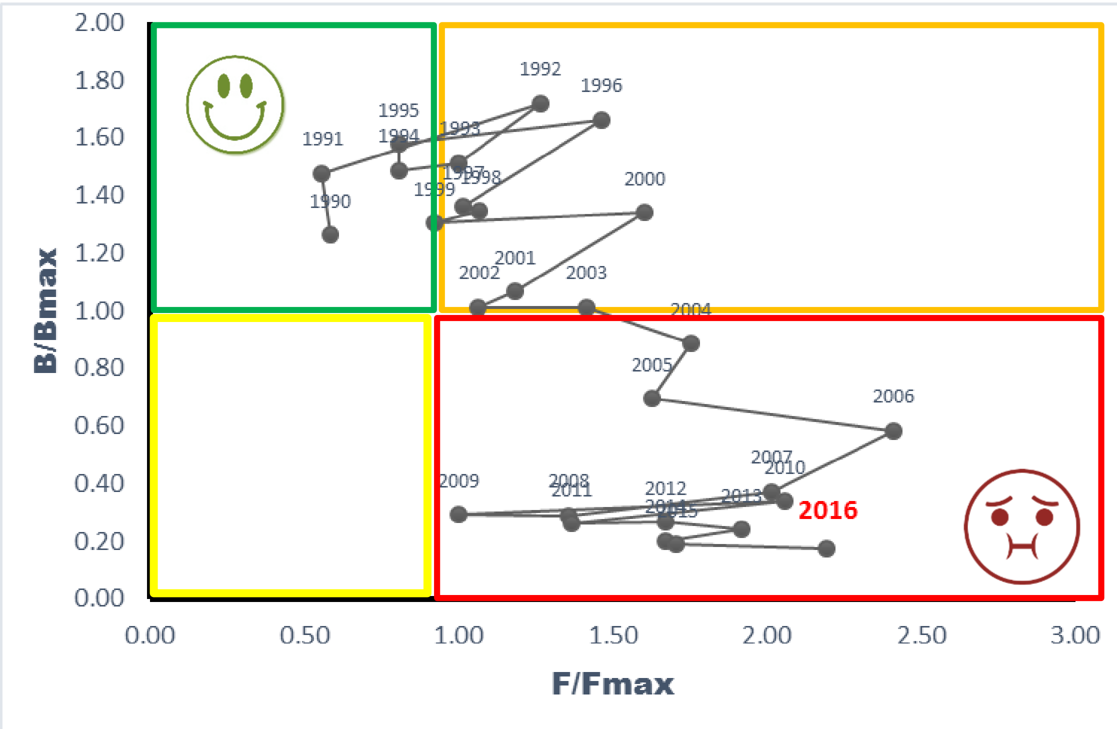

Figure 6 Control rule showing the trends of the relationship between biomass and fishing mortality over time for Ghana's small pelagic fishery.

The challenge for management is how to bring the data points in Figure 4, initially into the yellow box (reduced fishing mortality at or below the target reference point). Once that is achieved, we would expect that over a number of years that the biomass will start to rebuild and eventually get the data points into the green box, where we want the fishery to be, coming full circle to the early 1990s period. This will require years of sustained and reduced fishing pressure but it is the first step to achieving a healthy fishery that can sustain higher annual yields (landings) and provide greater revenues over time. The question is how to get there. This is addressed in the following section.

Scenarios to ending overfishing and rebuilding fish stocks

Status Quo Scenario Projections

Figure 7 depicts the status quo scenario extrapolation where fishing pressure remains the same and catch levels continue at a constant rate 20,000 MT per year. In this case the stock will crash (virtually no stock left in the ocean) by 2020.

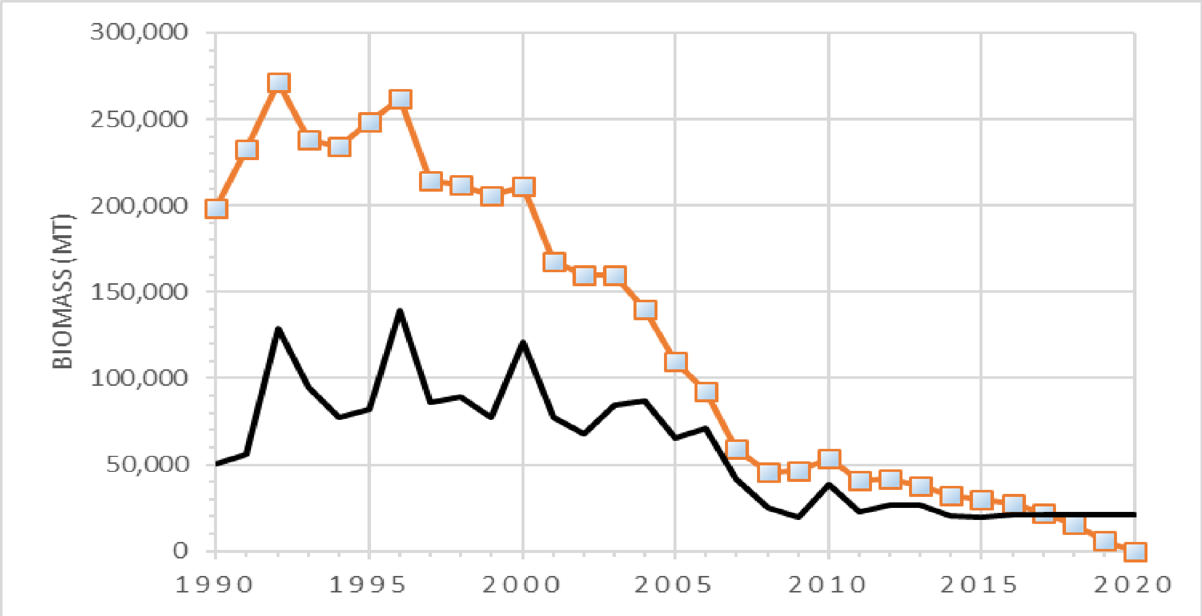

Figure 7 Status quo projection of the small pelagic stocks (orange line and Box points) with catch (black line) kept constant at >20,000 mt per year.

Rebuilding Scenario and Projections at the Target Reference Point for Fishing Mortality of F=0.4

If fishing mortality is reduced to F=0.4 beginning in 2018 (Figure 8), the small pelagic biomass is projected to be rebuilt by 2030 with a confidence interval based on output from the ASPIC model (CV=0.52).

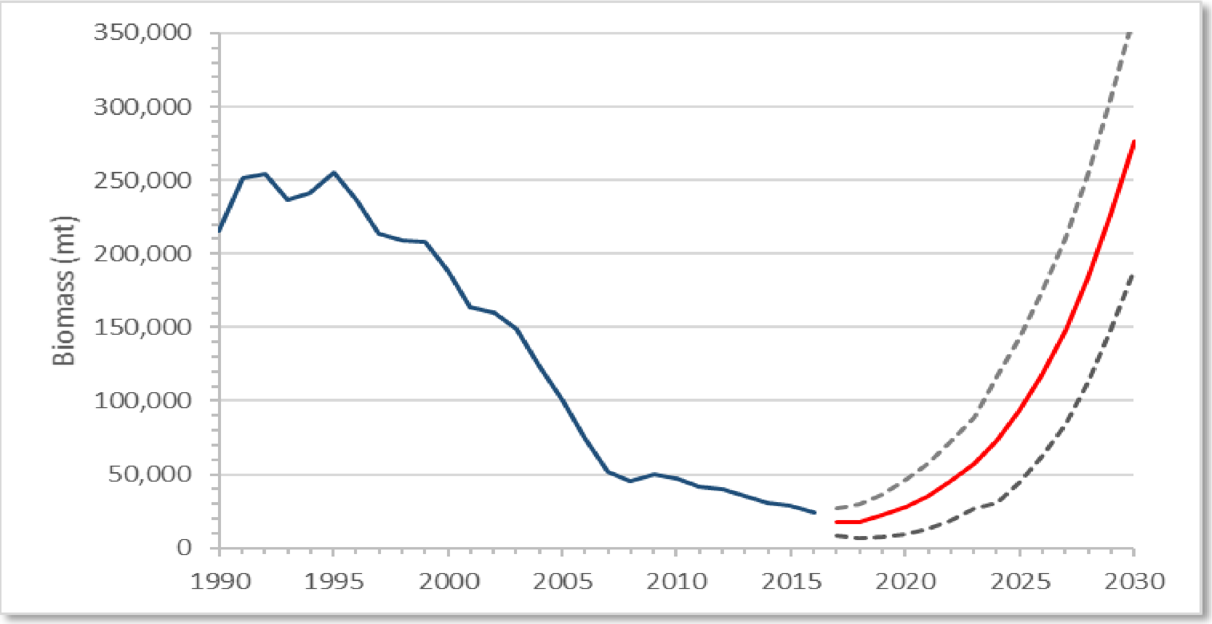

Figure 8 Biomass rebuilding scenario under F=0.4

If landings increased by 4.5 times the current level, current revenues from small pelagic landings can increase from GHC 60,000,000 per year to GHC 270,000,000 per year by 2030.

Assuming that fishing mortality is reduced to F=0.4 beginning in 2018 (Figure 8), the small pelagic landings are projected to reach 90,000 MT by 2030 (Figure 9) with a confidence interval based on output from the ASPIC model (CV=0.52). With current landings at approximately 20,000MT, this represents a more than fourfold increase in current annual landings, adding approximately 70,000 MT of high quality low cost food protein supply, locally produced into the local food supply chain. This will help offset the high level of fish importation into the country and could result in a 36% percent reduction in imports over current levels. This is a much faster and higher level of buildup of locally produced fish food supply compared to aquaculture trends where current yield is about 40,000 tonnes.

If landings increased by 4.5 times the current level, at a price of GHC 3 per kg of small pelagic fish, current revenues from small pelagic landings can increase from GHC 60,000,000 per year at current landing levels to GHC 270,000,000 per year by 2030 (1 kg = GHC 3). This represents an increase of GHC 210,000,000 per year in additional revenues being injected into coastal fishing communities annually. With approximately 100,000 fishermen along the cost, this is an additional GHC 2,700 per fisherman per year, over GHC 7 per day, and enough revenue to likely pull tens of thousands of coastal fisherfolk out of poverty, reversing the increasing poverty trends occurring now due to the collapse of the fishery.

Clearly, by ending overfishing, the fishery sector can make significant gains and contributions to food supply, sustained employment and poverty reduction in fishing communities.

A World Bank report indicated that incomes of canoe fishers has dropped by 40% over the last decade, that US$50,000,000 is lost annually due to poor management and overfishing, and that government expenditures on management are very low and are only 0.2% of annual revenues, compared to 17% allocated in OECD countries. More than 29,000 new jobs could be created in the marine-capture fishery sector if the additional value (US$50,000,00) in lost economic opportunity is recouped. *($50,000,000/$1,707 [Ghana's per capita GDP] = 29,290).*

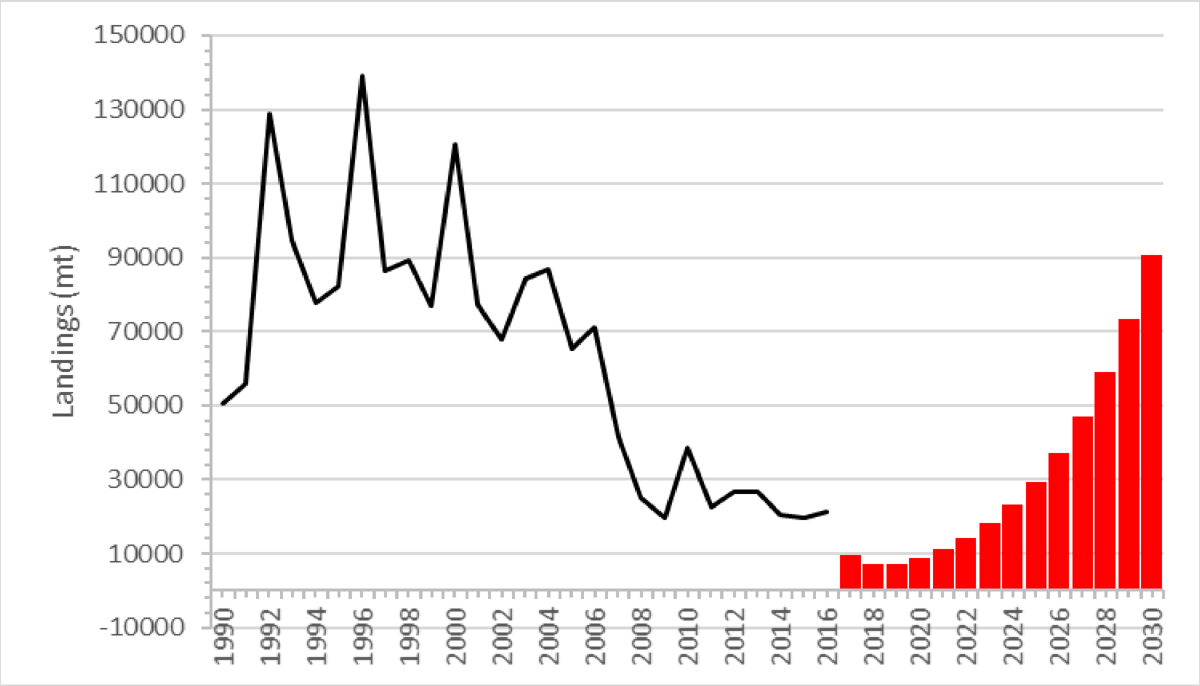

Figure 9 Changes in annual landings under a F=0.4 scenario.

RECOMMENDATIONS

In order to rebuild the small pelagic stocks and increase annual landings, The STWG recommends that the Fisheries Commission should implement the management measures called for in the national marine fisheries management plan (2015-2019) including:

1. End open access in the artisanal fisheries,
2. [1]Complete the canoe registration,
3. Implement a fishing licensing program for the artisanal fisheries,
4. Implement the additional fishing holiday as proposed by the F2F* initiative,
5. Implement co-management policy to include stakeholders in a transparent and systematic process.
6. Increase enforcement capacity and resources.

[1] F2F is a Fisherman to Fisherman consultation process initiated by SFMP to build consensus relative to fisheries management activities.

In addition the STWG recommends:

> A one-month closure on all fleets (canoes, inshore and industrial fisheries – except tuna). August has been selected as the month to yield the most return for rebuilding small pelagic resources. It coincides with the peak spawning period which allows the broodstock to reproduce and juveniles to survive and replace the lost biomass. The STWG presented full proposal to the Fisheries Commission to end overfishing and begin the rebuilding process based on closed season in 2016 (Lazar, Yankson, Blay, Ofori-Danson, Markwei, Agbogah, Bannerman, Sotor, Yamoa, Bilisini, 2016).

Short-lived species, such as small pelagics, can grow or decline quickly in response to fishing pressure, and this rapid decline in productivity often requires similarly rapid and drastic interventions by fisheries managers to reverse the trends. Notwithstanding environmental changes, the small pelagic stocks continue to be driven to collapse, as may already be the case with the round sardinella in Ghana.

At this time, it is uncertain whether these measures (closed season and effort control measures) will be sufficient to meet the F_{msy} target reference point. Further work needs to be done to estimate the full suite of effort reduction measures needed to achieve that target. However, these measures will start to move the fishery towards the F_{msy} target and to progress toward ending overfishing of the small pelagic fishery in Ghana. By ending overfishing and with further effort reduction measures, the biomass targets for sustaining higher yields of annual catches from the fishery can be achieved.

The STWG can develop an operational plan and budget for full implementation and monitoring the impacts of the seasonal closure, should the MoFAD and FC approve the recommendation.

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ANNEX 1 MODEL DIAGNOSTICS

The surplus production model was run 2000 times involving calibrated CPUE indices, nested in spatial strata and parameter format (constant, blocked and added an environmental factor). The model performance is presented below by a plot of process error residuals of the model in Figure 10. Overall the model with calibrated CPUE performed better than that used without taking into account the changes in fishing performance, including net and boat size and engine power. The data is highly variable but showed no bias in the parameter estimates. Several aspects of small pelagics' biology are known to be sensitive to temperature with abundance generally reduced during periods of high water temperatures. The model suggests reduction in productivity and operation of dispensatory mortality at low abundance. A likely mechanism is low intensity of the upwelling indices and a predator-prey relationship forced by overfishing and climate variations.

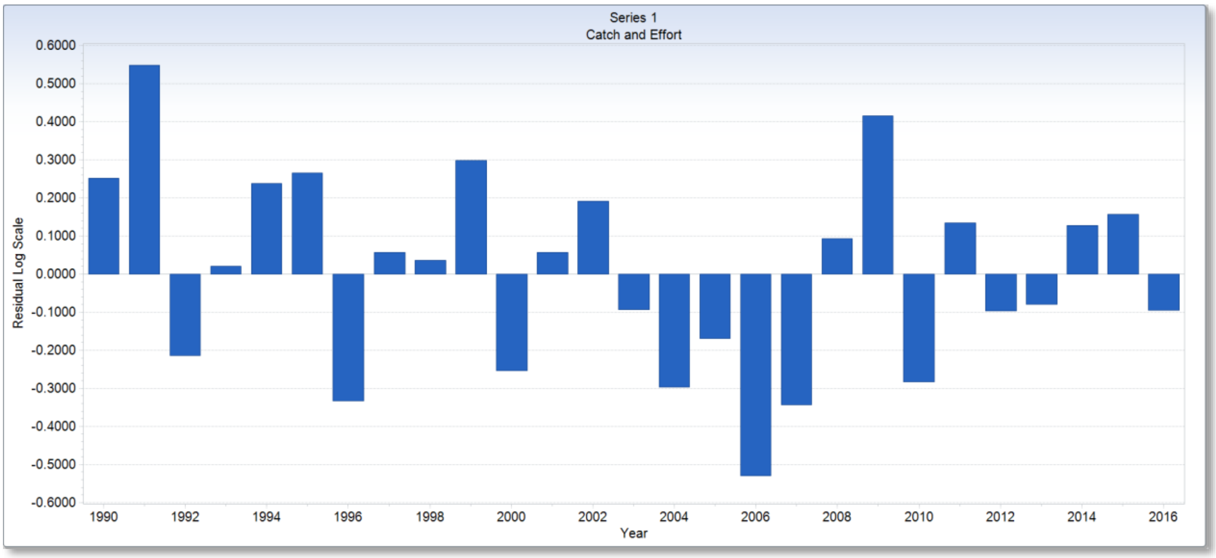

Figure 10 Production model residuals over the time series 1990 – 2016.

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The error is normal, high in 1991, 2006 and 2009, with no sign of consistent bias.

Parameters relating to unfished stock size (Bmsy) skewed to the left side of the distribution for biomass. This seemed unrealistic and possibly due to abrupt changes in catches and catchability over time (efficiency). Inclusion of historical data may provide the contrast needed for model performance and stability (Figure 11 and Figure 12).

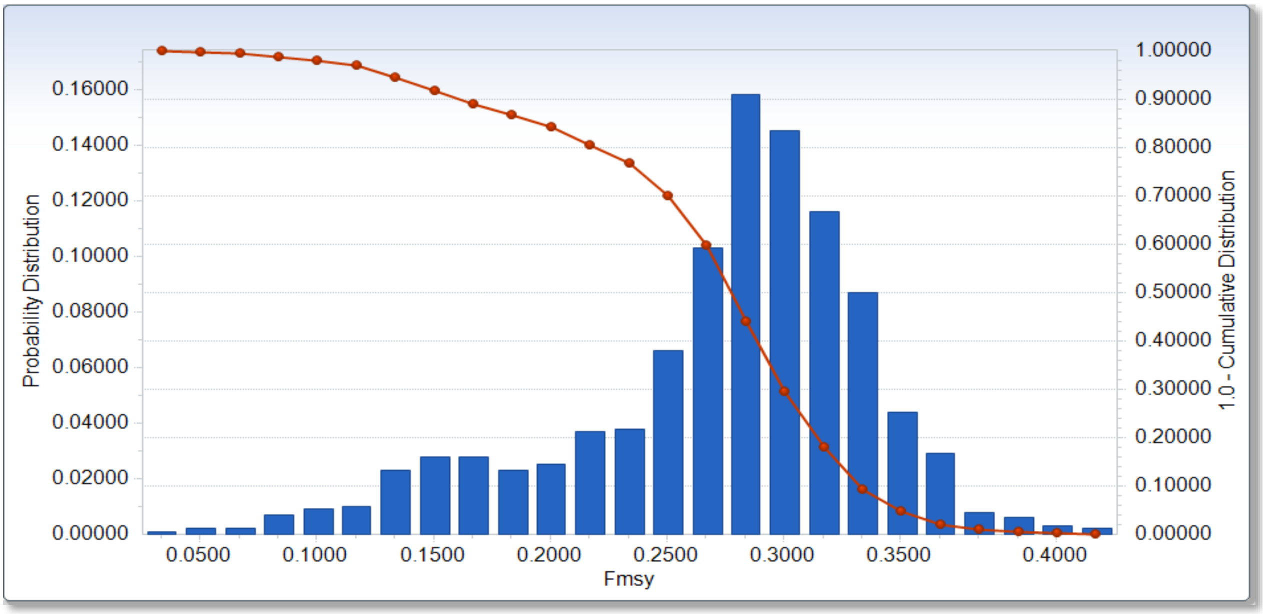

Figure 11 Bootstrap distribution of 1000 trials of estimates of fishing mortality at the maximum sustainable yield (Fmsy = 0.30)

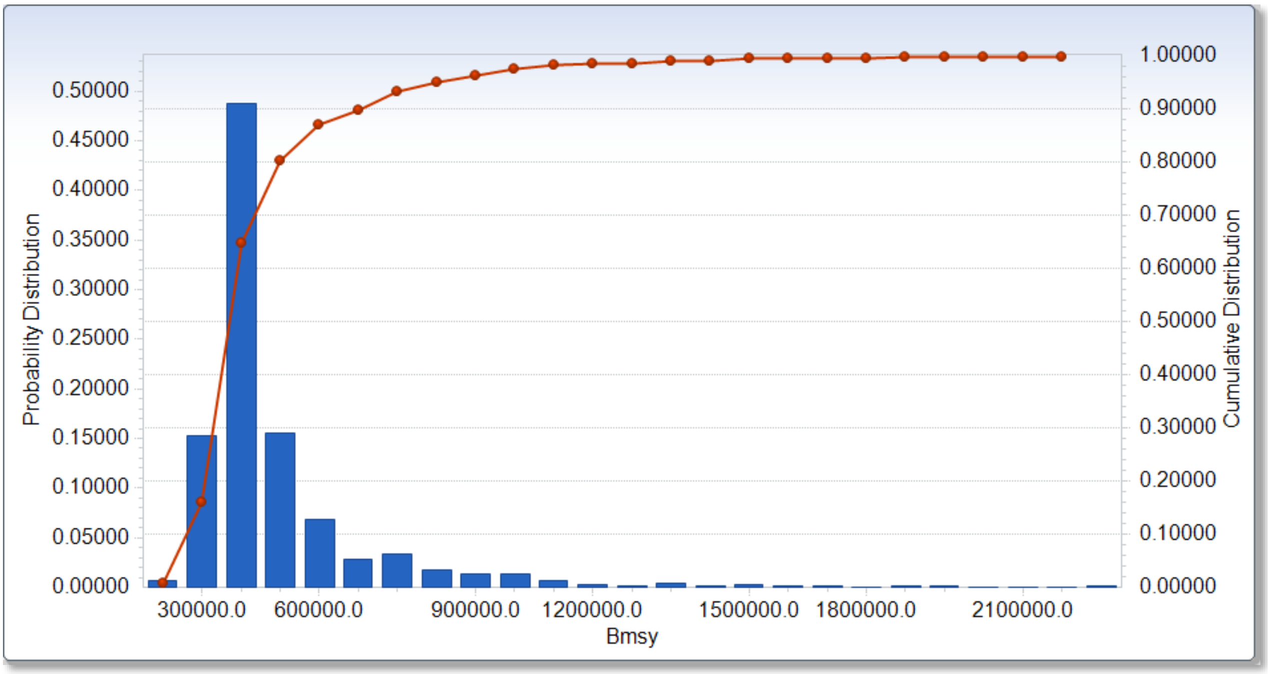

Figure 12 Bootstrap distribution of 1000 trials of estimates of biomass at the maximum sustainable yield (Bmsy = 310,000 metric tons = rebuilding target)