# SUSTAINABLE FISHERIES MANAGEMENT PROJECT (SFMP)

## Status of the small pelagic stocks in Ghana - 2016.

JULY, 2017

This publication is available electronically in the following locations:

*The Coastal Resources Center*

http://www.crc.uri.edu/projects_page/ghanasfmp/

*Ghanalinks.org*

https://ghanalinks.org/elibrary search term: SFMP

*USAID Development Clearing House*

https://dec.usaid.gov/dec/content/search.aspx search term: Ghana SFMP

**For more information** on the Ghana Sustainable Fisheries Management Project, contact:

USAID/Ghana Sustainable Fisheries Management Project
Coastal Resources Center
Graduate School of Oceanography
University of Rhode Island
220 South Ferry Rd.
Narragansett, RI 02882 USA
Tel: 401-874-6224 Fax: 401-874-6920 Email: info@crc.uri.edu

**Citation**: Lazar, N., Yankson, K., Blay, J., Ofori-Danson, P., Markwei, P., Agbogah, K., Bannerman, P., Sotor, M., Yamoah, K. K., Bilisini, W. B. (2017). Status of the small pelagic stocks in Ghana - 2016. Scientific and Technical Working Group. USAID/Ghana Sustainable Fisheries Management Project (SFMP). Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island. GH2014_ACT150_CRC. 16 pp.

**Authority/Disclaimer:**

Prepared for USAID/Ghana under Cooperative Agreement (AID-641-A-15-00001), awarded on October 22, 2014 to the University of Rhode Island, and entitled the USAID/Ghana Sustainable Fisheries Management Project (SFMP).

This document is made possible by the support of the American People through the United States Agency for International Development (USAID). The views expressed and opinions contained in this report are those of the SFMP team and are not intended as statements of policy of either USAID or the cooperating organizations. As such, the contents of this report are the sole responsibility of the SFMP team and do not necessarily reflect the views of USAID or the United States Government.

**Cover photo**: *Sardinella aurita* (Credit: Najih Lazar)

## Detailed Partner Contact Information:


**USAID/Ghana Sustainable Fisheries Management Project (SFMP)**
**10 Obodai St., Mempeasem, East Legon, Accra, Ghana**

**Telephone: +233 0302 542497 Fax: +233 0302 542498**

| | |
|---|---|
| Maurice Knight | Chief of Party maurice@crc.uri.edu |
| Kofi Agbogah | Senior Fisheries Advisor kagbogah@henmpoano.org |
| Nii Odenkey Abbey | Communications Officer nii.sfmp@crcuri.org |
| Bakari Nyari | Monitoring and Evaluation Specialist hardinyari.sfmp@crcuri.org |
| Brian Crawford | Project Manager, CRC brian@crc.uri.edu |
| Justice Odoi | USAID Administrative Officer Representative Jodoi@usaid.gov |

Kofi.Agbogah
kagbogah@henmpoano.org
Stephen Kankam
skankam@henmpoano.org
Hen Mpoano
38 J. Cross Cole St. Windy Ridge
Takoradi, Ghana
233 312 020 701

Andre de Jager
adejager@snvworld.org
SNV Netherlands Development Organisation
#161, 10 Maseru Road,
E. Legon, Accra, Ghana
233 30 701 2440

Donkris Mevuta
Kyei Yamoah
info@fonghana.org
Friends of the Nation
Parks and Gardens
Adiembra-Sekondi, Ghana
233 312 046 180

Peter Owusu Donkor
Spatial Solutions
powusu-donkor@spatialdimension.net
#3 Third Nautical Close,
Nungua, Accra, Ghana
233 020 463 4488

Thomas Buck
tom@ssg-advisors.com
SSG Advisors
182 Main Street
Burlington, VT 05401
(802) 735-1162

Victoria C. Koomson
cewefia@gmail.com
CEWEFIA
B342 Bronyibima Estate
Elmina, Ghana
233 024 427 8377

Lydia Sasu
daawomen@daawomen.org
DAA
Darkuman Junction, Kaneshie Odokor
Highway
Accra, Ghana
233 302 315894

Gifty Asmah
giftyasmah@Daasgift.org
Daasgift Quality Foundation
Headmaster residence, Sekondi College
Sekondi, Western Region, Ghana
233 243 326 178


**For additional information on partner activities:**

| | |
|---|---|
| CRC/URI: | http://www.crc.uri.edu |
| CEWEFIA: | http://cewefia.weebly.com/ |
| DAA: | http://womenthrive.org/development-action-association-daa |
| Daasgift: | https://www.facebook.com/pages/Daasgift-Quality-Foundation-FNGO/135372649846101 |
| Friends of the Nation: | http://www.fonghana.org |
| Hen Mpoano: | http://www.henmpoano.org |
| SNV: | http://www.snvworld.org/en/countries/ghana |
| SSG Advisors: | http://ssg-advisors.com/ |
| Spatial Solutions: | http://www.spatialsolutions.co/id1.html |

## 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 |

# TABLE OF CONTENTS

## CONTENTS



## LIST OF FIGURES



## LIST OF TABLES

# INTRODUCTION

This report provides an update of the status of the small pelagic fish stocks in Ghana through 2016. 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. The fish stock assessment was reviewed by the STWG in January 2017.

In this report we use the best available scientific information to show the status of the stocks in Ghana. Although small pelagic stocks extend beyond the borders of Ghana's EEZ, we assume, for management purposes only, that the landings from Ghana form a single small pelagic stock. We recognize that this assumption is not true; however, since the landings of Ghana represent a large share in the region of the Gulf of Guinea, the status of this stock will be indicative of the rest of the stock outside the boundaries of Ghana.

This assessment establishes new biological and management indicators or reference points for the purpose of monitoring the status of the stock and the impact of fisheries management actions. The revised management indicators were the results of the addition of new fishing effort data which were calibrated to account for the changes in gear efficiency overtime. The STWG agreed to maintain the initial biological references points for biomass (B) and fishing mortality rates (F) estimated in 2015. (See Lazar, N, Yankson K, Blay J., Ofori-Danson P., Markwei P., Agbogah K., Bannerman P., Sotor M., Yamoa K. K., Bilisini W. B., 2017).

The trends of declining fish stocks continue to be a major concern for fisheries stakeholders in Ghana. The rapid development of coastal pelagic fisheries over the past four decades is at the center of this decline. The biomass of many small pelagic stocks has drastically fallen at alarming rates due primarily to overfishing and overcapacity. 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 continues to decline as biomass became depleted and the cost of a fishing trip increased as time at sea and fuel consumption increased.

The 2015 stock assessments were performed using a surplus production model employing non-equilibrium and dynamic approaches (see Lazar *et al*., 2017), in which the effort data series were not calibrated and measured by direct observations of the number of purse seine canoes. These data driven models are often criticized for their inability to measure changes in catchability (lack of measuring the changes in efficiency over time). In this report we provide a new approach to model configuration by calibrating the effort using information obtained from a semi-structured survey conducted by Hen Mpoano. The survey uses local knowledge of experienced fishermen to reconstruct historical perspectives relative to fishing units (size of the canoe, size of the net, crew size, outboard motor HP, and other factors). (Lazar N., Asare C., Nortey D. D. N., Kankam S., & Agbogah K., 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. They have common biological and ecological traits and are processed and consumed dried or smoked. Biological and ecological backgrounds were included in Lazar *et al.,* 2017. They have common biological and ecological traits and are processed and consumed dried or smoked.

# STOCK UNIT DEFINITION

Small pelagic species caught in the southern Fishery Committee for the Eastern Central Atlantic (CECAF) region from Guinea to Angola are not known to have distinct biological differentiation of more than one stock. However, for management purposes and in the absence of information on stock identification, the FAO/CECAF scientific Working Group assumes the existence of four stocks of small pelagics in the southern CECAF area:

- Northern zone (Guinea-Bissau, Guinea, Sierra Leone and Liberia).
- Western zone (Côte d'Ivoire, Togo, Ghana, Togo and Benin).
- Central zone (Nigeria and Cameroon).
- Southern zone (Gabon, the Democratic Republic of the Congo, the Congo and Angola).

We define a sub-unit within the south Western stock represented by Ghana's fisheries and indicative of the entire stock.

# DATA SOURCES

## Landings and effort

The artisanal purse seine 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 10 mm 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 2015 at 19,608 tonnes (Figure 1). This represents 14% of the highest recorded landings of 1996 (138,955 tonnes). The average zero catch (vessel spending more than 20 hours searching for fish and returning with no catch) has increased. Preliminary estimates show more than 25% of vessels in Tema returned to harbor without catch. (Personal communication).

The rapid decline of landings suggests that there is an overfishing situation in Ghana's small pelagic fisheries. It is corroborated by the presence of small fish sizes in the catch which are noticeable in almost every landing site due to the use of smaller mesh sizes averaging 0.5 cm. This decline in landings made fishermen to increase the size of their nets and increased with it the number of fishermen needed to handle these larger nets. These changes resulted in a significant increase in efficiency per canoe (unit of effort) by 55% over 40 years (Table 1).

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 (1990-2015). We included the preliminary results of the 2016 frame survey (Dovlo E., Amador K., Nkrumah B., 2016) to account for the changes in number of fishing units. However, the size of the canoe, crew and nets increased over this time series and so did its efficiency. Therefore the fishing effort was calibrated in kW-units using local knowledge information to account for these changes in fishing efficiency.

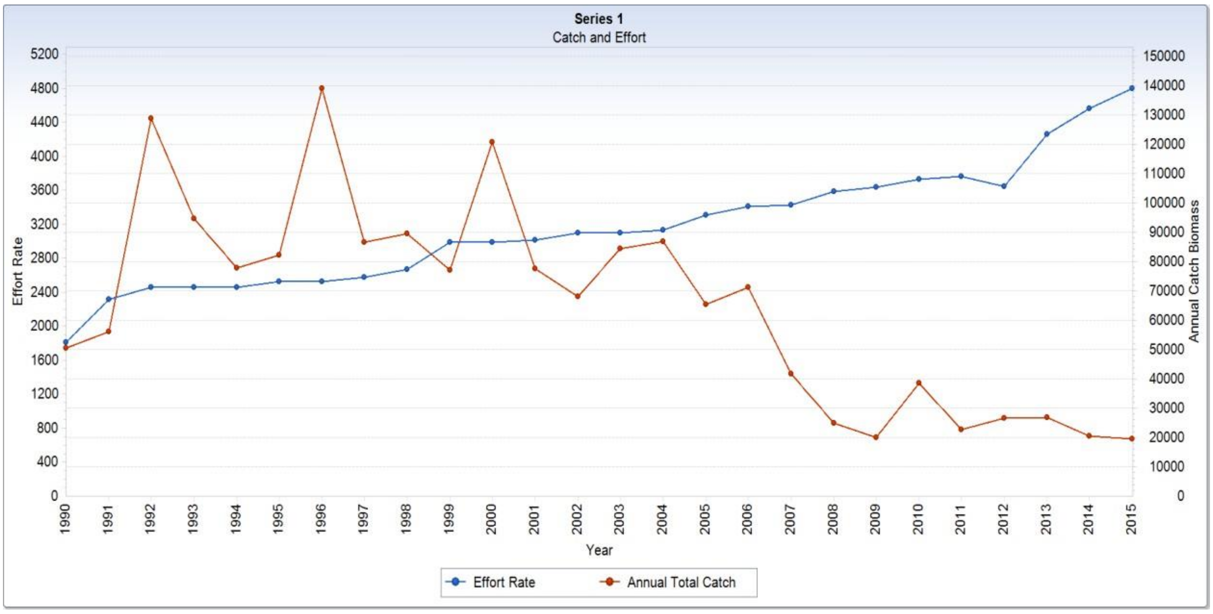


**Figure 1 Total landings of small pelagic stocks (Sardinella, Anchovies and Mackerel) in red and effort in number of canoes targeting small pelagics from 1990 to 2015 in Ghana**

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

| | 1970-1980 | 1980-1990 | 1990-2000 | Present |
|---|---|---|---|---|
| Fishing units | 2 | 2 | 2 | 2 |
| TOTAL LOA – Canoe | 10 | 13 | 1 | 22 |
| HP | 15 | 25 | 4 | 55 |
| KW (HP/1.34) | 11 | 19 | 3 | 41 |
| VCU(Vessel Capacity Unit) = (LOA*BR)+045*kw | 50 | 10<br>9 | 2<br>0 | 406 |
| Crew-carrying unit | 10 | 12 | 1 | 25 |
| Net-length (m) | 275 | 50 | 5 | 80 |
| Net-depth (m) | 30 | 25 | 2 | 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 | 3 | 10 |
| Days at sea per trip | 1 | 1 | 1 | 1 |
| Power of the canoe | 4.72 | 5.49 | 6 | 6.81 |
| Power of the seine (L*D*Crew | 11 | 12 | 1 | 14 |
| Total Unit power | 53.41 | 65.4 | 74.70 | 94.67 |
| Percent Change (70-80 as reference) | 0.00 | 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 (sardinella, anchovies and mackerel). The landings of the three major small pelagic species represent a strong indicator for the status of all small pelagic species. Fishing effort is represented by the number of canoes but calibrated to account for the changes of efficiency. We did not 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.

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

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
$\epsilon$ = 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 Hen Mpoano 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, 2004). 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.

## RESULTS

The model performed well and provided a reasonable level of precision (CV=0.07). 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 2015. Biomass in 2015 was estimated at 30,000 tonnes (Figure 2). This represents about 12% of the biomass needed to maintain sustainable exploitation of the stock. The rebuilding target $B_{msy}$ was estimated at 310,000 tonnes. The terminal relative biomass (B2015), expressed in a ratio of current biomass divided by $B_{msy}$, was estimated at 0.12.

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 2015. The fishing mortality in 2015 was estimated at F=0.8 (Figure 3). The recent Fridjoft Nansen research acoustic survey conducted in April 2016 in the waters of Ghana estimated similar levels of biomass for small pelagic stocks, noting a possible collapse of the sardinella stocks.

The average size of sardinella landed in 1998 was recorded by the Fisheries Scientific and Survey Division at 16 cm. The recent record of the average size was 9.5 cm in Tema in 2016, focusing mainly on juveniles of less than one year old. Signs of both heavy recruitment and growth overfishing are confirmed by these observations.

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. The original estimate of $F_{msy}$ is consistent with harvest rates applied in fisheries management of small pelagics.

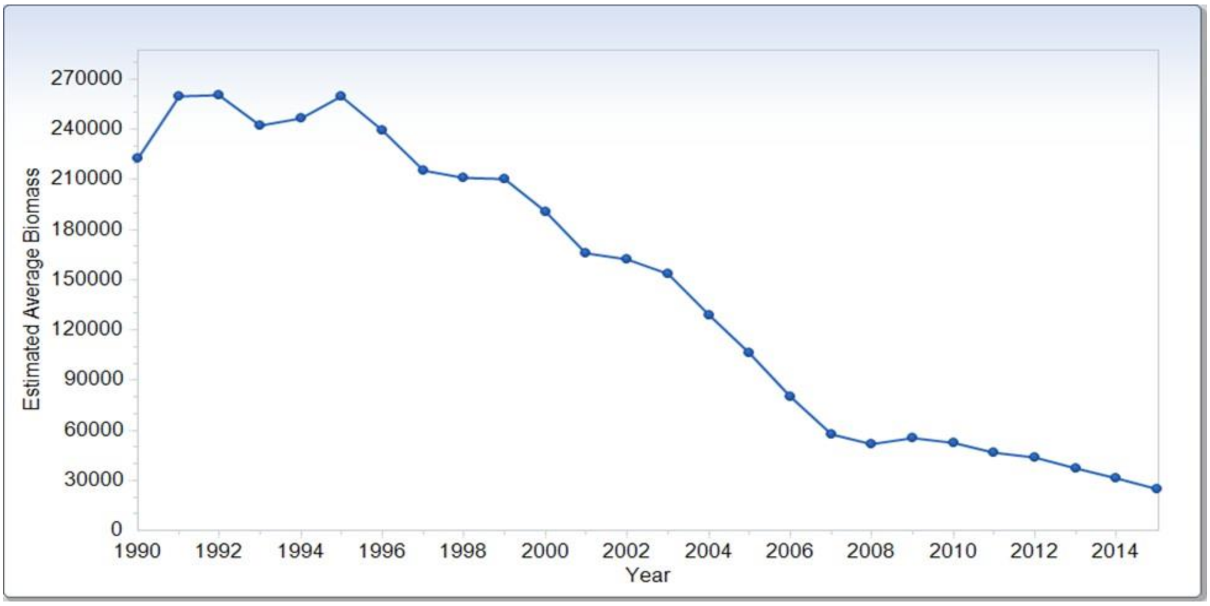


**Figure 2 Biomass trends of small pelagic fish stocks (Sardinella, Anchovies and Mackerel) in metric tons from 1990 to 2015 in Ghana.**

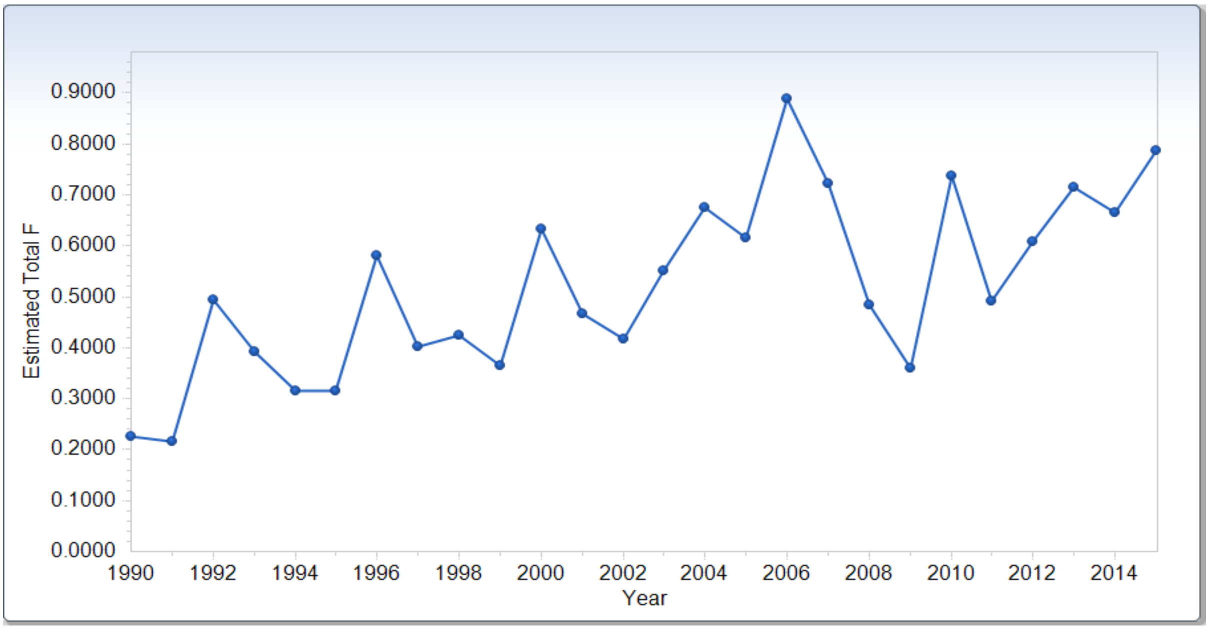


**Figure 3 Trends of fishing mortality of small pelagic stocks (Sardinella, Anchovies and Mackerel) from 1990 to 2015 in Ghana.**

We note no significant changes in $B_{msy}$, Therefore the rebuilding target of small pelagic stocks remains at 310,476 tonnes.

The comparison between 2014 and 2015 (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. This is due to model specifications, as CPUE is directly correlated to catchability (efficiency). Table 2 shows model results between 2014 and 2015.

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

| Biological reference points | 2014 | 2015 |
|---|---|---|
| $B_{msy}$ | 310,476 tonnes | 310,000 tonnes |
| $F_{msy}$ | 0.40 | 0.3 |
| $B_{current}$ | 182,726 tonnes | 30,000 tonnes |
| $F_{current}$ | 0.74 | 0.8 |

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.

## RECOMMENDATIONS

The STWG recommends that the Fisheries Commission should end open access and implement the canoe registration and licensing of the small artisanal fisheries.

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. The STWG presented a proposal to the Fisheries Commission to end overfishing and begin the rebuilding process. ( Lazar, N, Yankson K, Blay J., Ofori-Danson P., Markwei P., Agbogah K., Bannerman P., Sotor M., Yamoa K. K., Bilisini W. B., 2016 ). The proposal suggested a closed fishing season for one month for all fleets and all fisheries during the spawning period to allow broodstock to reproduce and juveniles to replace the lost biomass. The proposal remains under review and consideration by the Fisheries Commission.

At this time, it is uncertain whether these measures (closed season and capping canoe numbers) 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. Without ending overfishing by further effort reduction measures, the biomass targets for sustaining higher yields of annual catches from the fishery cannot be achieved.

## REFERENCES

Bannerman P., Quartey R. (2004). Observations of commercial light fishing operations in Ghana. Report of the Marine Fisheries Research Division (MRFD- Tema – Ghana). http://www.oceandocs.org/bitstream/handle/1834/1266/BANNERMAN%20improvements%20in%20the%20Ghanaian%20tuna%20statistics%20syste.pdf?sequence=1

Dovlo E., Amador K., Nkrumah B. (2016). Report of the 2016 Ghana marine canoe frame survey. Information report No 26. Fisheries Survey and Statistical Division. 85 pp.

Lazar N., Asare C., Nortey D. D. N., Kankam S., & Agbogah K. (2016). The Small Pelagic Fisheries Profile: Analysis of Regional Results. USAID/Sustainable Fisheries Management Project (SFMP). Narragansett, RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and Hen Mpoano. GH2014_ACT001_CRC. 39 pp. http://www.crc.uri.edu/download/GH2014_ACT001_CRC_FIN508.pdf

Lazar, N, Yankson K, Blay J., Ofori-Danson P., Markwei P., Agbogah K., Bannerman P., Sotor M., Yamoa K. K., Bilisini W. B. (2016). Proposal for closed fishing season for small pelagic fisheries in Ghana. Scientific and Technical Working Group of USAID/Ghana Sustainable Fisheries Management Project (SFMP). Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island. GH2014_SCI002_CRC. 17 pp. http://www.crc.uri.edu/download/GH2014_SCI002_CRC_FIN508.pdf

Lazar, N, Yankson K, Blay J., Ofori-Danson P., Markwei P., Agbogah K., Bannerman P., Sotor M., Yamoa K. K., Bilisini W. B. (2017). Status of the small pelagic stocks in Ghana (2015). Scientific and Technical Working Group of USAID/Ghana Sustainable Fisheries Management Project (SFMP). Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island. GH2014_ACT093_CRC 28 pp. http://www.crc.uri.edu/download/GH2014_ACT093_CRC_FIN508.pdf

Nansen. (2016). Cruise report of R/V Dr. Fritjof Nansen in Ghana - NORAD- FAO Project GCP/INT/003/NOR. EAF–N/2016/6. Fisheries Survey and Statistical Survey 92 pp.

# 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 4. 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.

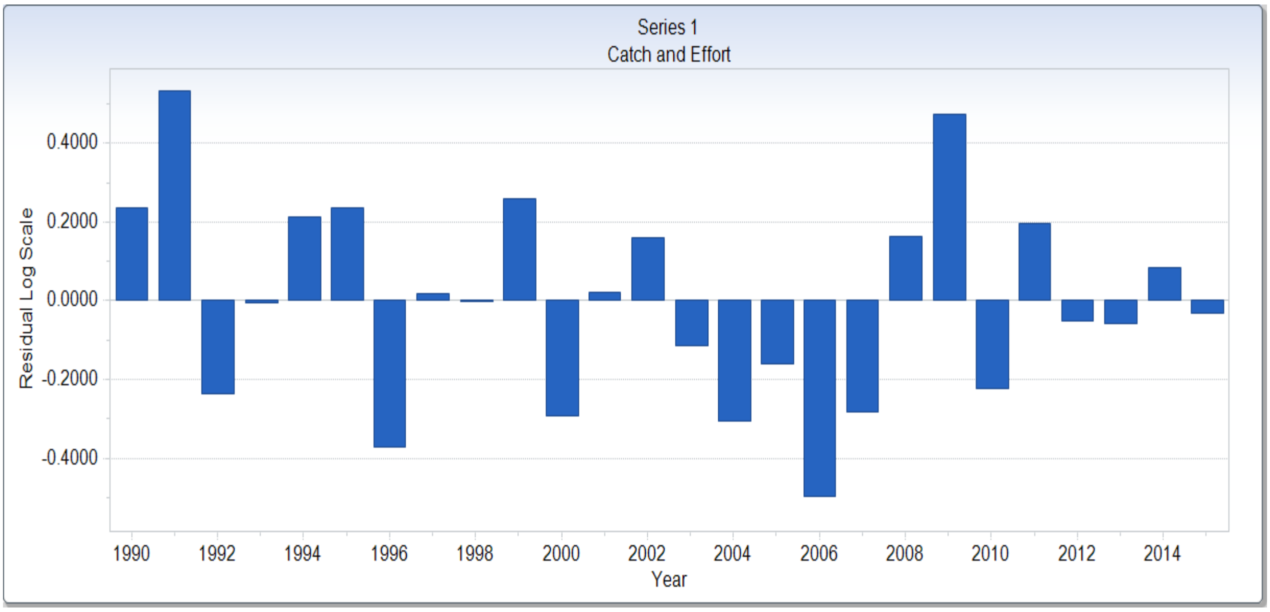


**Figure 4 Production model residuals over the time series 1990 – 2015.**

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 5 and Figure 6).

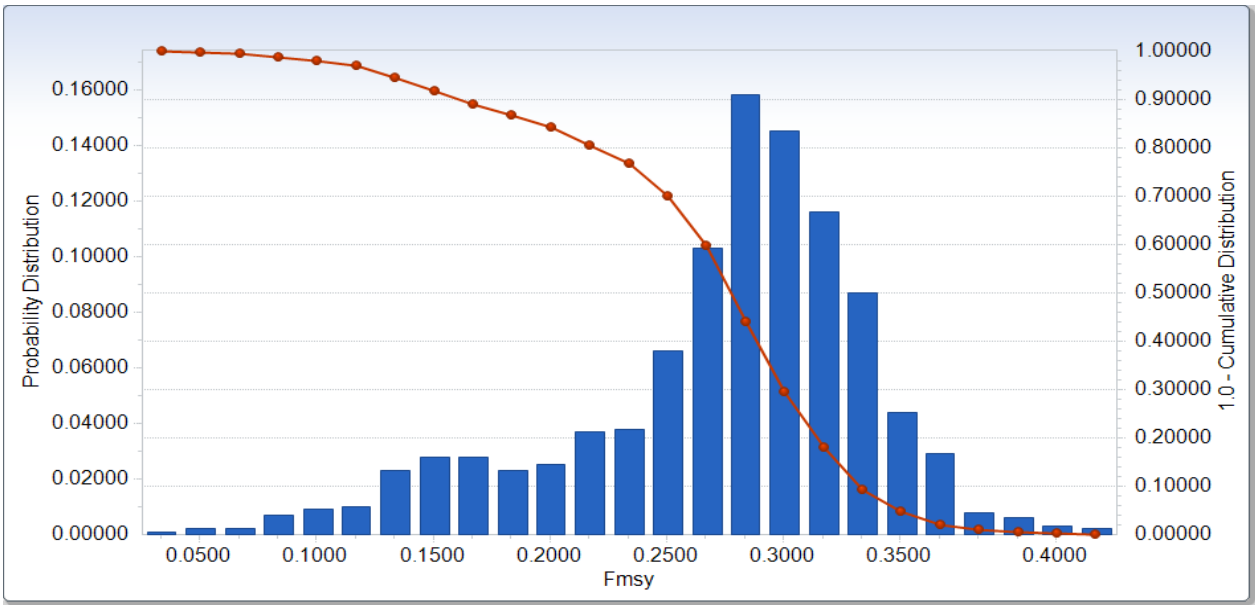


**Figure 5 Bootstrap distribution of 1000 trials of estimates of fishing mortality at the maximum sustainable yield (Fmsy = 0.30)**

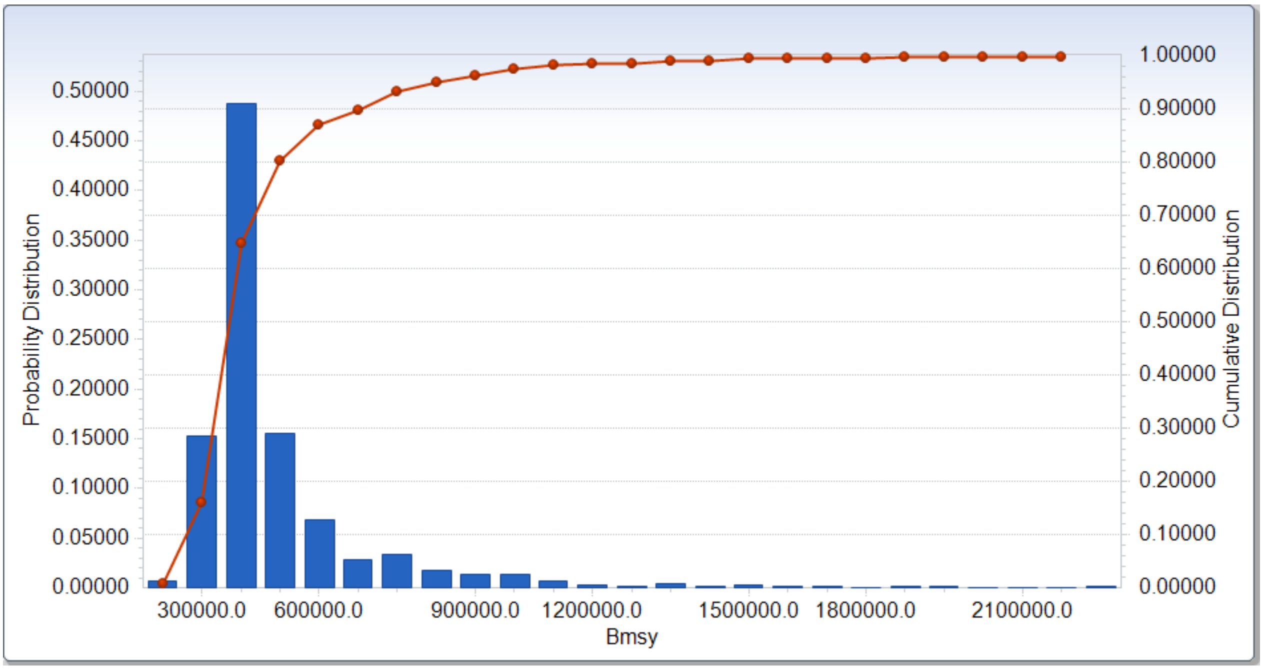


**Figure 6 Bootstrap distribution of 1000 trials of estimates of biomass at the maximum sustainable yield (Bmsy = 310,000 metric tons = rebuilding target)**