COST-BENEFIT ANALYSIS OF INTERVENTIONS FOR SUSTAINABLE ARTISANAL MARINE

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Interventions for Sustainable Artisanal Marine Capture Fisheries Management in Ghana

Ghana Priorities

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Abstract

Despite the artisanal fishery sector in Ghana creating employment for about 20% of the labor force, providing over 60% of animal protein and supporting livelihoods of fishing communities, while contributing over 15% to agriculture GDP, fish stocks are inappropriately managed leading to overcapitalization and overexploitation. Factors contributing to this menace include the open access nature of the management of the resource, which generates congestion externality and a race to the bottom; the use of illegal fishing gears, such as small mesh sizes to improve catch efficiency; and illegal targeting of artisanal stocks by industrial trawl vessels. It is evident that, without adequate management strategies, the stocks will collapse. In this report, three interventions – i.e., replacement of illegal/destructive fishing nets, training and subsidizing feed for aquaculture, and installation of video devices on trawl vessels -- have been proposed and a detailed benefit-cost analysis has been undertaken for each intervention to determine its social viability. It has been found that planting video devices generates the highest social net returns followed by the replacement of nets with illegal mesh sizes. These results are predicated on the relevant laws being appropriately enforced.

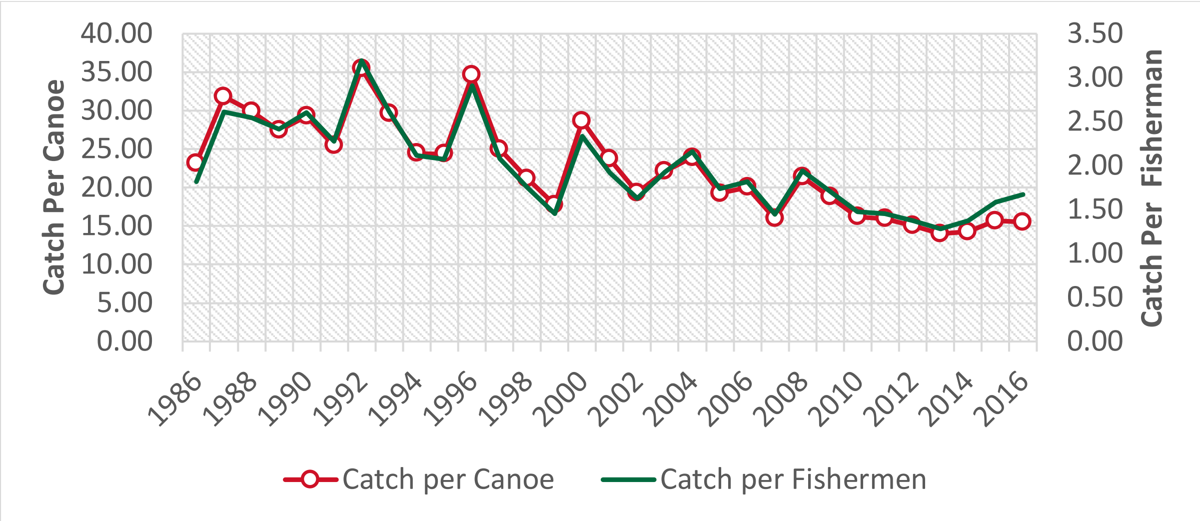
Policy Abstract

The Problem

Fish is an important source of animal protein in developing coastal countries, including Ghana. Within the West African region, fish protein constitutes about one-third of animal protein, which is more than twice the global average and just slightly more than on-half of Ghana's average. The fisheries sector employs and sustains the livelihoods of a significant number of the active labour force, including women who play key roles in the post-harvest value-chain creation. In Ghana, at least 3 million people, including half a million women, are working within the capture fisheries sector. In addition, within the country, the sector makes up about 15% of the annual total agricultural output (i.e., agricultural GDP).

The capture artisanal marine fisheries sector, which is one of the four marine fisheries sectors in Ghana, is by far the leading fisheries sector contributing over three-quarters of the total marine fish landings and about a third of total domestic landings. Yet, the sector has too many canoes. The fishing capacity is in excess of approximately 40%, implying a significant number of canoes must be decommissioned to maximise resource rent or profit. The excess capacity is worsened by Illegal, Unreported and Unregulated (IUU) fishing activities, including the use of destructive fishing gears by both artisanal and industrial fleets to improve catch efficiency. As shown in Fig. 1, beginning 1992 both the catch per canoe and fishermen have been declining rapidly overtime.

Fig. 1. Catch Per Boat and Per Fisherman in Ghana (1986 -2016)



The main targeted species of the artisanal fishermen are sardines, anchovies, and mackerel, commonly known as '*the people's fish*' owing to their contribution to animal protein in many households. The dominant IUU fishing among the artisanal fishers is the use of nets with very small mesh sizes. On the other hand, industrial trawl vessels that are licensed to fish in distant waters and target 'demersal species' that live on, or close to the bottom of the sea rather, illegally, target small pelagic species, freeze them into pellets and transship them at sea to middlemen. Currently, due to the biological overfishing, coupled with low aquaculture production, only 40% of the fish consumed in Ghana is produced locally.

In this study, three policy interventions have been proposed and analysed using a social benefit cost analysis to address the overfishing problem. These include replacement of illegal/destructive fishing nets, limiting the number of fishing boats while providing training and subsidizing feed for aquaculture, and installing video devices in the trawl vessels to regulate their illegal fishing activities. These interventions are supposed to be implemented by the government through the Ministry of Fisheries and Aquaculture Development (MoFAD).

Interventions

1. Replacement of illegal/destructive fishing nets

Nine in every ten artisanal marine fishermen in Ghana use illegal mesh sizes (Akpalu, 2007), some of which are as so small as 10mm in stretched diagonal to improve the efficiency of the fishing gear. Despite a clearly laid out penalty for violating the regulation, compliance rate is very low owing to inadequate enforcement. A plausible intervention is to replace all the illegal fishing nets with legal ones. In the short term, when the nets are replaced, harvest will reduce by 28% on average (Akpalu, 2008). However, since the stocks targeted are fast growing pelagic species, within a year, the average size of fish caught will be bigger, hence more valuable.

The cost elements of the intervention are:

- the cost of the new (approved) nets – GHS 165 million,
- expenditure on sensitizing the fishermen about the benefits of the policy – GHS 0.5 million and,
- the opportunity cost of lost rents to the fishermen within the first year GHS 101 million.

The corresponding benefit is the increased revenue from selling mature and valuable fish, which is more than twice the price of juveniles. This is worth GHS 189 million per year. Using a central discount rate of 8%, over a 10-year period, the intervention will generate approximately 5 times the social benefit over cost.

2. Limiting the number of canoes while providing training and subsidizing feed for aquaculture.

Profit in the marine capture fisheries is much lower than what it ought to be owing to excess capacity in the fishery. To maximize profit or resource rents, the number of canoes must be reduced to the level corresponding to the maximum economic yield (MEY). Doing so will increase rents for the remaining boats by GHS 107 million per year. However, this will lead to 40,000 jobs lost, with a corresponding loss of income equal to GHS 66 million per year.

The fishermen who will lose their jobs, as a result, will have to be incentivized to take up fish farming in ponds and cages. Since capture fishermen are often reluctant to shift to other economic activities, this intervention will come at a social and political cost, which must be accounted for. We surmise that an incentive compatible scheme equivalent to the forgone income of the displaced fishermen must be provided as part of this intervention (GHS 66 million).

It is expected that a fish farmer will start with one pond for the first two years, then progress to 2 ponds in the third and fourth year, then finally to 3 ponds in the fifth and sixth year. Since, on average, fish farming only becomes meaningfully profitable when the farmer has at least 3 ponds, within the first four years, the farmers will be supported. In the first two years they will be provided interest free loans and fish feed subsidy. In the third and fourth year, only feed subsidy will be required. After the fourth year, the project becomes profitable and will not require any further assistance. The benefit is the stock build up and the corresponding increase in rents in the captured fisheries sector. The BCR associated with this intervention is 1.2. The costs and benefits of the intervention are noted below:

	Costs (GHS, millions)				Benefits (GHS, millions)		
	Aquaculture paid by farmers	Government subsidy and extension	Displacement costs	Total	Aqua-culture revenue	Increased rent from marine stocks	Total
1 pond	262	106	66	434	219	107	326
2 ponds	388	38	66	493	437	107	544
3 ponds	517	2	66	585	656	107	763
4 ponds	646	2	66	714	875	107	982

3. Installing video devices in the trawl vessels

Like the artisanal fishery, industrial trawl vessels operating within Ghana's exclusive economic zone are too many. On average they lose about 52% of their potential rents/profits annually. In addition, the trawlers illegally target small pelagic species, freeze them into pellets, and transship them to boats operated by middlemen who in turn retail them to fish processors in fishing communities along the coast. The illegal practice, which is commonly known as *saiko*, is accelerating the depletion of pelagic stocks. *Saiko* fish is poor quality and does not compete with the fresh fish landed by artisanal boats. This intervention entails installing a video device 'FishEye of Trident' on each vessel, which will be monitored. The cost of the intervention is 12m up front in cameras with ongoing annual costs of 11m for monitoring staff.

It is estimated that artisanal profits could increase by almost three-quarters owing to the intervention. These are valued at 260m per year. Using a central discount rate of 8%, it has been found that installing video devices on trawl vessels generates the highest return. The

BCR indicates that the benefit accruing to planting a video device could be more than 20 times the associated cost, all else equal.

Table1. Summary of Costs and Benefits of Proposed Interventions

Intervention	**Discount Rate**	**Benefit (GHS millions)**	**Cost (GHS millions)**	**BCR**
Replacement of illegal gears	5%	1,457	254	5.7
	8%	1,266	247	5.1
	14%	984	234	4.2
Restricting fishing boats while providing training and subsidising feed for aquaculture	5%	5,291	4,424	1.2
	8%	4,465	3,786	1.2
	14%	3,275	2,858	1.1
Planting of video devices on Trawl vessels	5%	2,010	94	21.4
	8%	1,747	83	21.1
	14%	1,358	66	20.5

INTRODUCTION **1**

METHODS **4**

DATA **5**

Maximum Sustainable Yield and Effort 6

Maximum Economic Yield (MEY) and Effort in a Timeless Situation 7

THE BENEFIT-COST ANALYSIS **8**

INTERVENTIONS **9**

Replacement of illegal/destructive fishing nets 9

Costs and Benefits *9*

Limiting Fishing Effort while Providing Training and Subsidizing Feed for Aquaculture 12

Costs and Benefits *13*

Planting Video Devices on Trawl Vessels 15

Costs and Benefits *16*

CONCLUDING REMARKS **18**

REFERENCES **19**

APPENDIX A **21**

Introduction

Capture fish stocks, like other living resources, can replenish themselves and generate significant amount of wealth in perpetuity if catch rates are kept within reasonable limits. In most developing coastal countries, however, fish resources are managed as regulated open-access or, at best, common-pool resources, leading to overcapitalization, biological overfishing and rent dissipation (see e.g. Hardin, 1968, for a discussion on open-access resource management). Ghana's situation is classical, and without adequate interventions to address the overfishing problem, the nation's fish stocks are very likely to collapse. In addition to the declining catches, changes in catch composition of species have been observed over time, as well as the prevalence of small-sized fish in catches (personal communication of a chief fisherman and an executive of Ghana National Canoe Fishermen's Council).

In Ghana, the capture fisheries sector is made up of the marine and inland sectors, with the former contributing over 90 percent of total landings. The marine sector has three subsectors, namely; artisanal; semi-industrial; and industrial, which has trawl and tuna fisheries. The artisanal marine fishery is, by far, the most important sector in terms of output, Gross Domestic Product (GDP), employment, supply of animal protein and sustenance of livelihood in fishing communities. It contributes over 75 percent to total marine fish production and about a third to total domestic landings. The main species targeted are sardines, anchovies, and mackerel, which are small pelagic species commonly known as '*the people's fish'*. Secondly, if the entire value chain including fish processing and retailing, which has a multiplier effect of 2.5 (Chimatiro, 2010) is captured, the contribution to agricultural and total GDP could be as high as 15 and 3.5 percent, respectively. Thirdly, it is estimated that about 20 percent of the labor force (i.e., 3 million people) are employed by the sub-sector (Atta-Mills et al., 2004), with women accounting for 18 percent of the number. Furthermore, per capita annual fish consumption which was 27kg in 2006 declined to 21kg as at 2016. Despite the figure being lower than the recommended FAO average of 40kg (Ashitey and Flake, 2009), only 40 percent of the current consumption is produced locally (i.e., from capture and aquaculture) with the remainder imported.

In addition to the excessive fishing capacity (overcapitalization) in the artisanal fishery owing to the open-access nature of management, several fishermen employ illegal fishing techniques to improve their catch efficiency. The most dominant is the use of fishing nets that have much smaller than the mandated mesh-size of 25mm in stretched diagonal. A survey of the fishers revealed that about 90 percent use illegal mesh sizes, with the lowest being 10mm (see e.g., Koranteng, 1992; Lazar et al., 2017). The damage stems from catching juvenile stocks that could become bigger and more valuable in the future. Furthermore, trawl vessels that are licensed to fish in distance waters targeting ‘demersal species’ that live on, or close to the bottom of the sea rather, illegally, target small pelagic species, freeze them into pellets and transship them at sea to middlemen. A study found that in 2017, the small pelagic species caught constituted about 60% of the total landings of the trawl vessels (EJF, 2019).

As noted earlier, the consequences of the congestion externality due to open-access management of the artisanal stock, the use of illegal mesh sizes, and the illegal fishing activities of the trawl vessels have together resulted in a very high rate of depletion of the small pelagic stocks. Figure 1 illustrates the evolution of catches per boat and fisherman between 1986 and 2016. Clearly, both catch per boat and fisherman have been declining since 1992 when the catch per boat and fisherman were 35.44 and 3.19 mt, respectively. By 2016, both had declined to 15.52 and 1.67mt, respectively. Moreover, total artisanal landings have also been declining as shown in Fig. 2. Total catch was about 276,000mt in 2000, but declined steadily to about 180,000mt by 2016, affirming biological overfishing.

Fig. 1. Catch Per Boat and Per Fisherman in Ghana (1986 -2016).

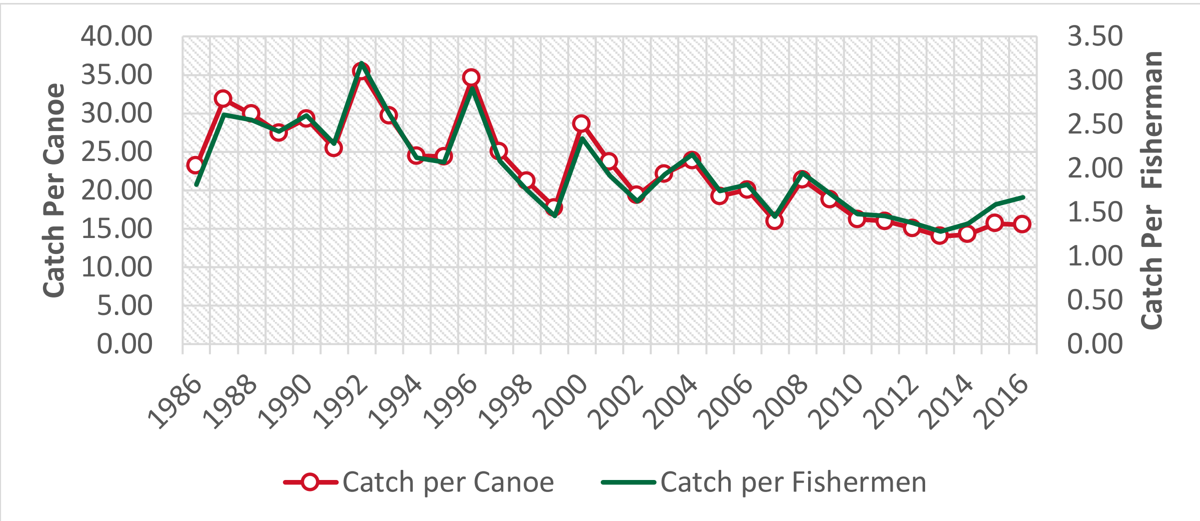
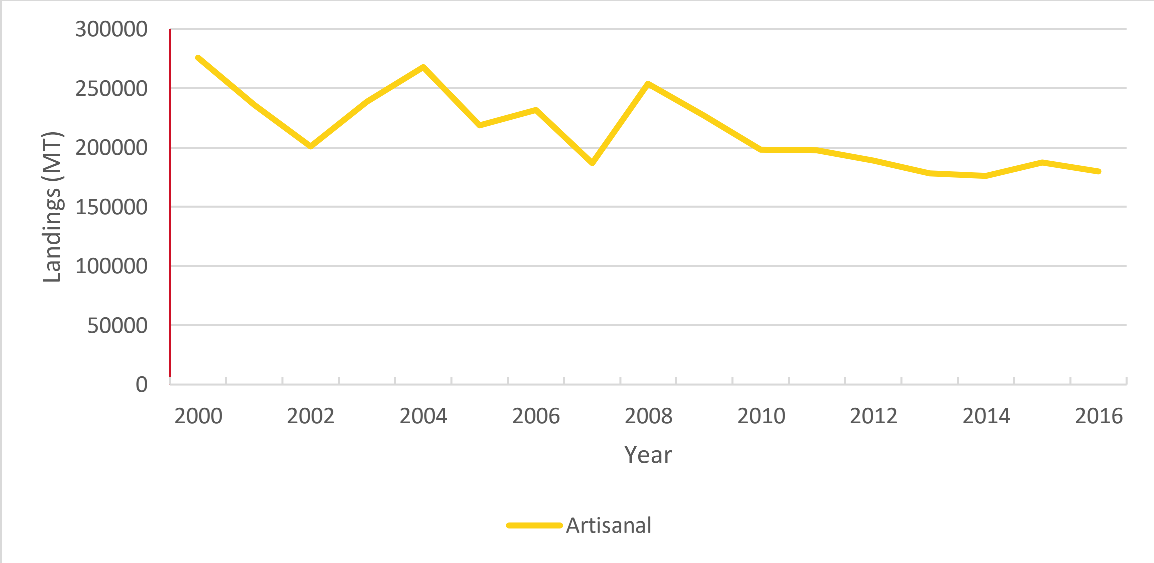


Fig. 2: Reported fish landings by Artisanal Marine Fleet (Source: Fisheries Commission, Ghana)



To address the overfishing problem, three interventions have been proposed and analyzed to determine how their social returns or benefits compare with the cost of implementing them. They are:

1. Replacement of illegal/destructive fishing nets
2. Limiting Fishing Effort while Providing Training and Subsidizing Feed for Aquaculture
3. Installing video devices in the trawl vessels

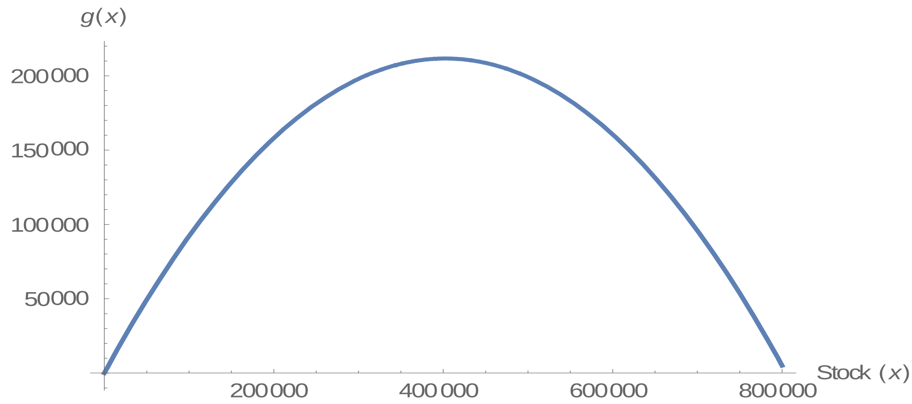
The results of these analyses indicate that, over a ten-year period and at any positive social discount rate, installing video devices generates the highest returns on investment (21 times at 8% social discount rate). This is followed by replacing nets with small mesh sizes (5 times at 8% social discount rate). Setting effort quotas whilst providing training on aquaculture to displaced fishermen and offering them subsidies, generated benefits 1.2 times the cost (at an 8% social discount rate).

In the next sections, a basic fisheries bioeconomic model has been discussed and estimated. This forms the basis for the analysis of each proposed intervention.

Methods

The analysis draws on a simple fisheries bio-economic model. Like other biological resources, fish stocks can replenish themselves if the rate of extraction does not exceed the intrinsic growth rate of the stock. Suppose the stock (biomass) of fish within the management area of Ghana, which is the exclusive economic zone, grows according to a logistics function. Let x and $g(x) = rx\left(1 - x/k\right)$ denote the fish stock and the logistics function, respectively; where k is environmental carrying capacity and r is the intrinsic growth rate. Fig. 1 represents the growth function.

Fig. 3. The Logistic Growth Function of Fish Stocks



From the figure, there is no growth if the stock level is zero or is at its maximum. Furthermore, the highest growth rate is realized when the stock level is one-half of the carrying capacity (i.e., the maximum stock level). In the absence of human predation or harvest, the evolution of the stock is given by the following equation:

$$x_t = x_{t-1} + g\left(x_t\right) \tag{1}$$

where x_{t-1} is the previous period's stock. The equation stipulates that the current stock is the sum of the previous stock and the growth without the period. In steady state, a given stock level is maintained, hence $x_t = x_{t-1} = x^*$ and $g(x) = 0$. This implies that the equilibrium stock will be at its environmental carrying capacity $x^* = k$.

Now, suppose human predation occurs and it follows a Gordon-Schaefer function (Gordon, 1953, 1954; Schaefer, 1954) specified as: $h\left(x_t, E_t\right) = qE_t x_t$, where E_t signifies fishing effort index (e.g. number of boats) and q is the catchability coefficient, which can be assumed constant. The corresponding fish stock evolution equation becomes:

$$x_t = x_{t-1} + g\left(x_t\right) - h(x_t, E_t) \tag{2}$$

In steady state, $\dot{x} = 0$ (i.e., $h(x, E) = g(x)$) and equation (2) generates the following equilibrium stock level:

$$x^* = k\left(1 - {}^{q}\!/_{r}\, E\right) \tag{3}$$

An equilibrium harvest or sustainable yield (y) function is obtained if equation 2 is substituted in the Schaefer-harvest function. That is:

$$y = y(E) = qkE\left(1 - \frac{q}{r}E\right), \tag{4}$$

Let $\hat{\alpha}\left(= qk\right)$ and $\hat{\beta}\left(= {}^{q^2k}\!/_{r}\right)$ so that equation (4), plus an additional term ε_t, is rewritten as (5).

$$y_t = \hat{\alpha}E_t - \hat{\beta}E_t^2 + \varepsilon_t, \tag{5}$$

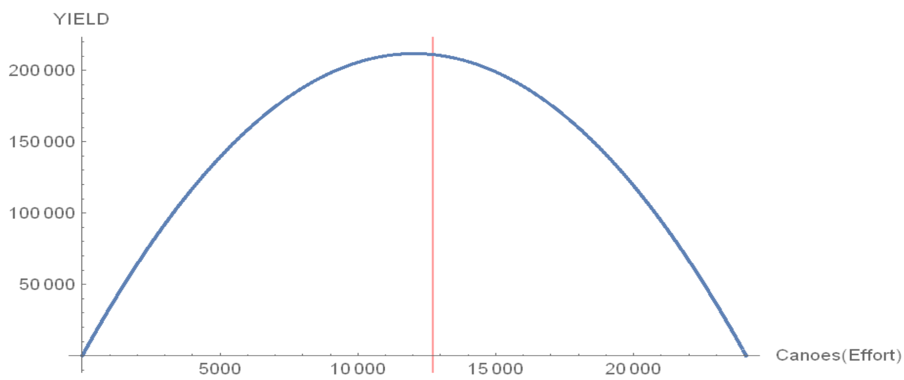
where $\hat{\alpha}$ and $\hat{\beta}$ are two parameters that can be estimated, given catch and effort time series data; ε_t denote a normally distributed error term. Since only two parameters are estimated, we need the value of either q, k or r to recover the remainder. Since the intrinsic growth rate of the dominant species targeted by the artisanal fishers is known, it is used to compute the environmental carrying capacity and the catchability coefficient.

Data

The data for the analysis was obtained from the Fisheries Scientific Survey Division (FSSD), which is under the Ministry of Fisheries and Aquaculture Development (MoFAD). It is a time series data on fishing effort, proxied by the number of artisanal fishing boats, and the corresponding catch quantities spanning the period 1973 to 2016. As noted earlier, the annual catch per fishing boat has been on a general decline, indicating that the fishery is overcapitalized and over-exploited. The data on fishing effort and catch used for the analysis is in Table A4 at Appendix A. The mean values of the fishing effort (boats) and catch within the periods 1986 and 2016 are 10,191 boats and 22,1760.6 mt, respectively.

Using the catch and effort data, the sustainable yield function has been estimated and the results are reported in Table A1 at Appendix A. The F-statistic indicates that the line is a good fit at 1% significant level, and the two parameters estimated are statistically significant also at 1% level. Furthermore, the signs of the coefficients of effort and the square of effort are positive and negative, respectively, implying the quadratic function is an inverted-u shaped. Based on the estimated parameters and the known value of the intrinsic growth rate (i.e., $r = 1.05$), the carrying capacity of the management area is estimated at approximately 805,000 tons and the catchability coefficient is 0.00004368 (see Table A2 at Appendix A). From Fig. 4 the Sustainable Yield (SY) is represented by the concave function and the vertical line represents the current (2017) level of effort (12,728 boats).

Fig. 4. Sustainable Yield Function for Artisanal Fisheries in Ghana (1973-2016)



Maximum Sustainable Yield and Effort

Maximum Sustainable Yield (MSY), which is the maximum predation that can sustain the stock in perpetuity, is defined at the turning point of the quadratic function. From the Sustainable Yield (SY) function (i.e., equation 5) and Fig. 1, the MSY and the corresponding effort (i.e., number of fishing boats) are calculated as:

$$\partial \hat{Y}_t / \partial E_t = 0 \Rightarrow E_{MSY} = \hat{\alpha} / 2\hat{\beta} = r / 2q, \qquad (6)$$

$$MSY = y\left(E_{MSY}\right) = {}^{rk}\!/_{4}, \qquad (7)$$

where ${}^{\partial \hat{Y}_t}\!/_{\partial E_t}$ is the first order derivative of the yield function with respect to the fishing effort. Using the estimated parameter values, the MSY is calculated to be 211,678 tons and the corresponding effort is 12,042 boats. As shown in Fig.1, the effort corresponding to the MSY is lower than the current levels of effort implying overcapitalization; hence harvest is lower than what is obtained at the MSY level.

Maximum Economic Yield (MEY) and Effort in a Timeless Situation

The SY and MSY are biological necessities that do not indicate whether (or not) the fishery is profitable. Thus, two economic parameters (the price of fish and cost of catching the fish) are necessary for our bioeconomic analyses. The profit function for fishery is:

$$\pi\left(E\right) = py(E) - cE = pqkE\left(1 - \frac{q}{r}E\right) - cE \qquad (8)$$

where p is the perfect competitive price of fish, hence $py(E)$ is total revenue from catch; and c is cost per unit effort, with cE being the total cost of fishing. Maximizing the profit function with respect to the fishing effort (i.e., number of boats) gives the following:

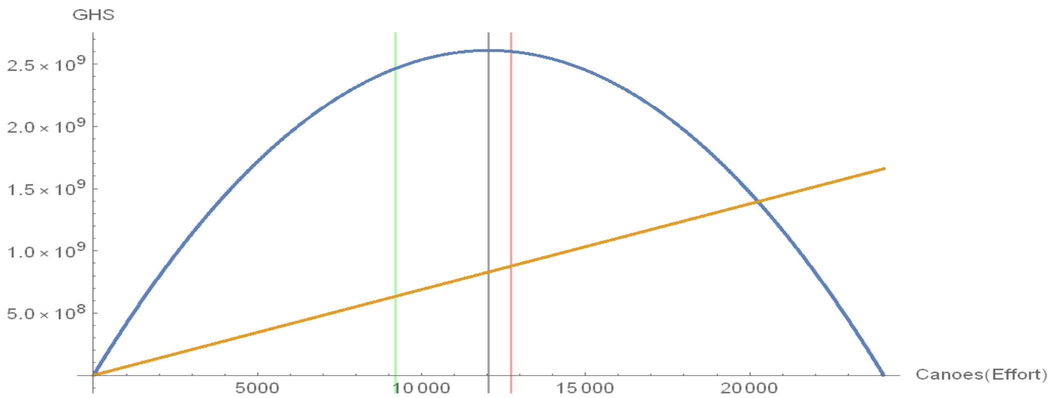
$$\partial\pi\left(E\right)\!/_{\partial E} = 0 \Rightarrow E_{MEY} = \frac{r}{2q}\left(1 - \frac{c}{pqk}\right) \qquad (9)$$

and

$$MEY = Y\left(E_{MEY}\right) = \frac{r}{4k}\left(k^2 - \left(\frac{c}{pq}\right)^2\right) \qquad (10)$$

where MEY refers to Maximum Economic Yield, which is the catch level that generates the maximum profit or resource rent. Figure 5 illustrates the catch and effort levels corresponding to the MEY (i.e., the green vertical line) based on the cost of fishing (i.e., the upward sloping yellow line), MSY (i.e., the blue vertical line), and the current level of effort (i.e., the red line). Thus, profits are maximized if only 9,188 boats are permitted to fish at the current rate of extraction. This figure is lower than MSY level of effort, which is 12,041 boats.

Fig. 5. MSY and MEY for Artisanal Fisheries in Ghana (1973-2016)



The Benefit-Cost Analysis

The benefits and the costs associated with each intervention are used to determine whether (or not) it is socially beneficial. Each value is discounted at annual rates of 5%, 8% and 14%, following the prescription by the Copenhagen Consensus Center. The benefit-cost ratios are calculated as:

$$BCR = \frac{PV_0(Benefits)}{PV_0(Costs)} \tag{11}$$

where $PV_0 = \sum_{t=0}^{T} FV_t (1+r)^{-t}$, PV is the present value, FV is the future value, r is the discount rate and t is the time. If for any intervention, the calculated BCR is greater (less) than 1, then the society gains (losses) from such an intervention. As a result, it is rational to implement interventions for which the BCR is greater than one and discard those for which it is less than one. In this study, the benefit-cost analyses are carried out over a ten-year period. In the following section, the elements of social costs and benefits of each intervention are explained and the BCR computed.

Interventions

The interventions aimed at reducing the overexploitation of the capture artisanal marine fishery will pass through either the biophysical parameters – i.e., environmental carrying capacity, intrinsic growth rate, catchability coefficient -- or economics parameters – i.e., price of fish or cost per unit harvest. The interventions are discussed in turn.

Replacement of illegal/destructive fishing nets

Over the years, the number of canoes in the artisanal marine capture fishery sector has increased significantly. The growth in overcapitalization has led to biological overfishing with a heightened risk of stock collapse. Moreover, the situation is further aggravated by about 90 percent of the fishers using illegal mesh sizes (Akpalu, 2007), some of which are as so small as 10mm in stretched diagonal to improve the efficiency of their fishing gear. The fishing laws of Ghana forbid the use of mesh sizes less than 25mm in stretched diagonal. Despite the prescribed penalty of GHS 600 (50 penalty units) or imprisonment for three months, or both, for violating the regulation, compliance rate is very low due to inadequate enforcement. Although other regulations, such as barring the use of light aggregation equipment, poison or dynamite fishing, are violated by artisanal fishers, the mesh size regulation is the most frequently violated. A possible solution is to replace all the illegal fishing nets with the legal ones. The average prices of the fishing nets across the regions are provided in Table A3 at Appendix A. A survey found that the catchability coefficient, hence harvest, will reduce at 28% on average if the net is replaced (Akpalu, 2008). However, since the stocks targeted are fast growing pelagic species, within a year, the average size of fish caught will be bigger, hence more valuable.

Costs and Benefits

The nets deployed by the artisanal fishers include pursing nets, beach seine, lobster net, ali net, drifting net and line. Of these, Poli/Watsa, Ali and Beach Seine are primarily illegal nets. According to the canoe frame survey of 2016, there are 3085 Poli/Watsa nets, 1873 Ali nets and 1074 beach seine. The table (A2) at Appendix A contains details of the regional distribution of the nets. In total, an estimated amount of GHS165million will be spent on replacing the net. Since it is very unlikely the fishermen will accept the policy without some sensitization, based on the budget of the Ministry of Fisheries and Aquaculture Development (MoFAD), the one-time cost is estimated to be GHS 485,000. In addition, within the first year, before the fish grows and become more valuable, the opportunity cost of lost rents to the fishermen is calculated at the 28%. This cost is estimated at GHS 102 million. Despite the fact that fishermen overall are better off in the long run from this intervention, liquidity constraints might prevent them from being able to absorb even a modest one-off reduction in yearly income. Therefore, some of this cost might have to be borne by the government, either as a direct cash grant or as a loan. The total costs of the intervention are therefore GHS 267 million, all incurred in the first year.

However, after the first year, the bigger-sized fish commands a higher price and total rents from the fishery increase. From data obtained from the retailers, the weighted average price of matured small pelagic species is more than twice the price of juveniles. Figures 6 and 7 illustrate the changes in rents within the first year and after the first year, respectively. From the first figure, the red vertical line indicates the number of boats currently in the fishery and the blue concave function is the total revenue function. A reduction in the catchability coefficient generates the pink concave function. The gap between the blue and the pink functions along the vertical line constitutes the loss within the first year of the intervention. Beginning the second year, as fish becomes bigger, the price per kg increases. As a result, the position of the pink curve changes. The annual rent obtainable from the intervention, after the first year, is measured by the gap between the blue and the pink curves along the vertical red line respectively. This gives the benefit associated with the intervention, which is estimated at GHS 189 million per annum. This translates to an increase in profit per boat of 52%.

Fig 6. Replacing small mesh nets, but the average size of fish has not changed.

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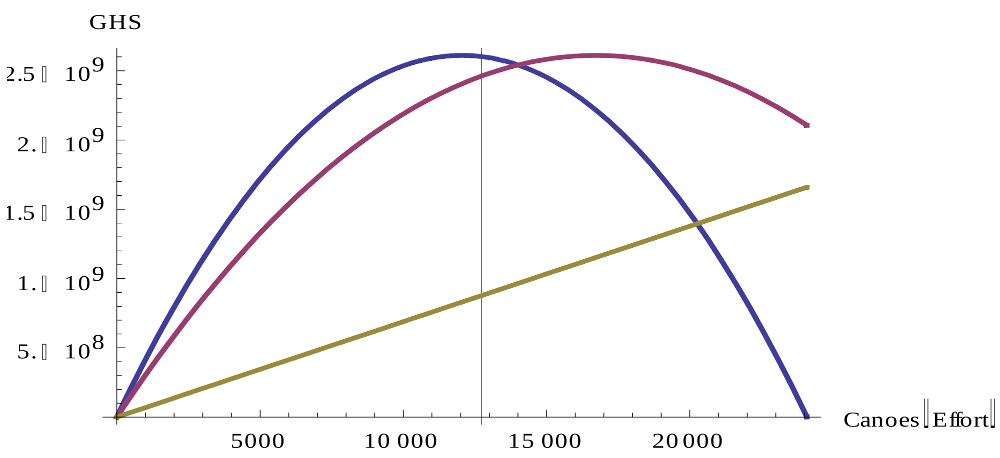
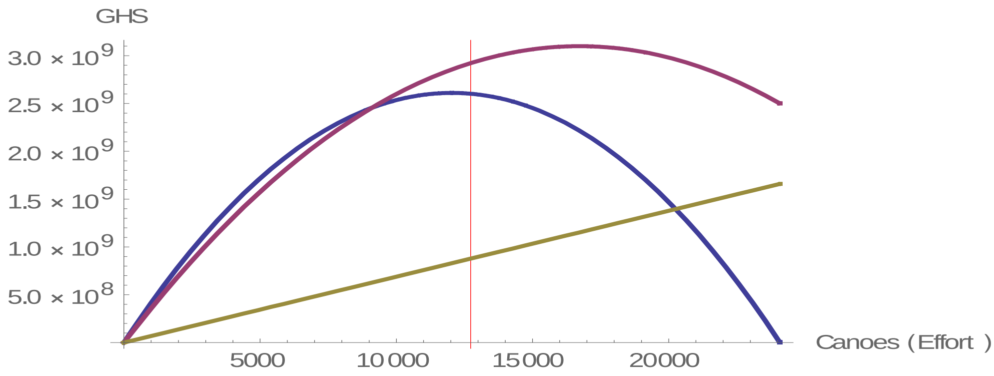


Fig 7. Replacing small mesh nets, and the average size of fish hence price has changed.



In summary, for a one-off cost of GHS 267 million, approximately 40% of which will be borne by fishermen, future rents will increase by 52%, generating benefits worth GHS 189 million annually. Over a 10-year horizon total benefits are valued at GHS 1,266 million at an 8% discount rate. The benefit-cost ratio (BCR) for this intervention is about 5 at the central discount rate of 8%. The results at other discount rates are presented in Table 1 below.

Table 1: Summary of Costs and Benefits of Replacing Illegal Fishing Net

Discount Rate	Benefit (GHS million)	Cost (GHS million)	BCR
5%	1,457	254	5.7
8%	1,266	247	5.1
14%	984	234	4.2

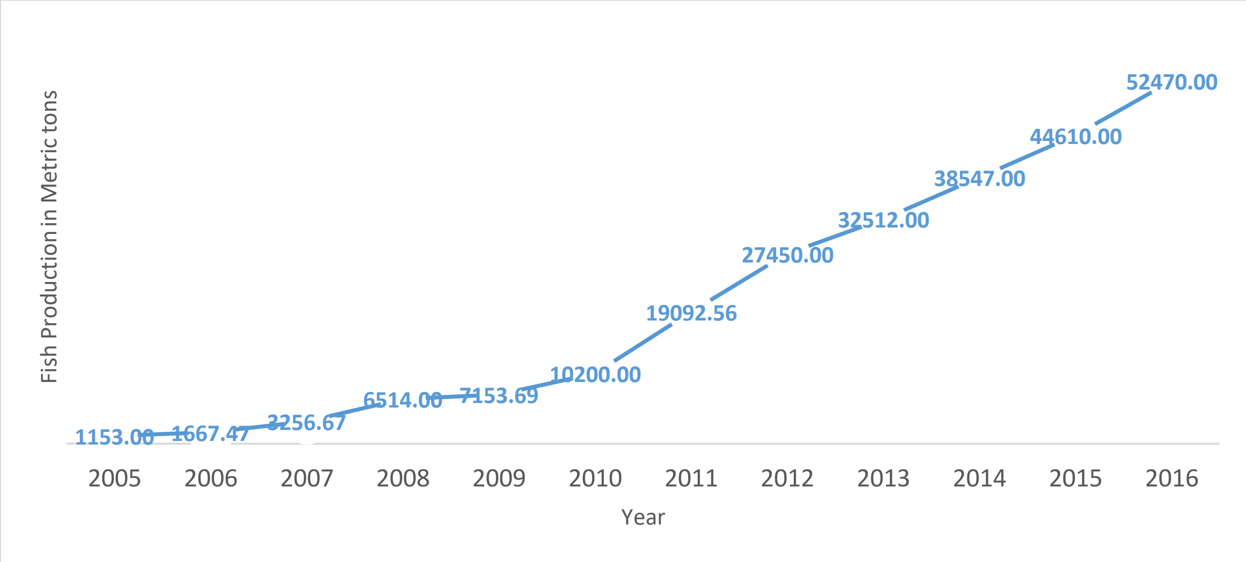
The results of this intervention rest on a number of key assumptions, the most important of which is ongoing compliance with laws that mandate minimum net size. It is hoped that the provision of legal nets for free (and destruction of old nets) along with sensitization activities including communicating the substantial future benefits of compliance, will provide the necessary impetus for fishermen to adhere to the laws. Even if there is eventual recidivism the benefits are substantial enough that the intervention 'breaks even' after 1.4 years. This is plausible learning from the outcome of the implementation of the last closed season, which to the best of our knowledge, did not record any violations. Notwithstanding these assumptions, the findings provide a strong basis for discussion on effectiveness of the proposed management policy.

Limiting Fishing Effort while Providing Training and Subsidizing Feed for Aquaculture

As noted earlier, there is excess capacity in the capture marine fisheries. To maximize resource rents, the number of canoes must be reduced to the level corresponding to the maximum economic yield (MEY). This, however, implies that a significant number of vessels must be decommissioned, leading to job losses. The fishermen who will lose their jobs will be encouraged to go into pond or tank culture at the minor-scale, after receiving the requisite training and with the support of extension services. Pond or tank culture is proposed because the coastal areas are not endowed with lakes and rivers. Since capture fishers are often reluctant to shift to other economic activities, this intervention will come at a social and political cost if not incentivized. We surmise that an incentive compactible scheme equivalent to the forgone rents of the displaced fishermen must be accounted for as part of the cost of intervention

Currently, aquaculture contributes significantly to total fish production in Ghana. It began before the nation's independence but on a very small scale. The decreasing capture fisheries production, since the 1990's, has brought aquaculture to prominence. Between 2005 and 2016, the sub-sector's contribution to domestic fish production rose from 0.3 to 11.28 percent, respectively (Akpalu et al., 2018). The 2010 population census, which is the most recent, indicates the number of aquaculture operators is 48,000. Two species are commonly farmed in Ghana: Tilapia and catfish. However, tilapia is highly preferred, and hence commands a very high price (GHS12 or US$2.50 per kg), which is at least twice that of the world market (Akpalu et al., 2018). As a result, tilapia is the main species cultivated with Ghana currently ranked as the 13th largest tilapia producer in the world. The figure 8 illustrates the evolution of aquaculture production in the country.

Fig. 8. Aquaculture Production in Ghana in metric tons (2005-2016).



Source: Fisheries Commission of Ghana

In Ghana, tilapia is typically farmed in cages, which constitutes over 88% of the total aquaculture production; ponds and tanks make up 7.3% and dams/dugouts/reservoirs account for the remainder (i.e., 4.7%) (Fisheries Commission, 2016). Aquaculture in Ghana is done on a large, medium, small or minor scale depending on the number of cages of volume of production. The small-scale operators have between 4 and 16 cages and those with less than 4 cages are referred to as minor-scale farmers (Akpalu et al., 2018). Although the price of fish is high, the cost of production is excessive owing to the high feed cost, which constitutes about 70-80% of total cost of production (Akpalu et al., 2018).

Regarding the proposed intervention (i.e., pond/tank culture) we surmise that the farmers will cultivate tilapia beginning at a minor-scale and progress eventually to a small-scale.

Costs and Benefits

From the analysis presented earlier, the effort (number of canoes) corresponding the maximum economic rents from the fishery is 9,188 boats, whiles the number of boats associated with the MSY is 12,728. The excess of 3,540 boats if multiplied by 11 crew per boat, on average, implies that 38,940 fishermen will be unemployed. On the other hand, the reduction in effort will elevate total annual rents of the remaining boats by GHS 107 million. However, for the fishermen of the canoes that are decommissioned to take up aquaculture, the foregone annual profit of about GHS66 million, which is considered an adjustment cost, must be transferred to the effected fishermen annually. The net gain to society from effort reduction is GHS 41m, which is the difference between the gains to the boats that remain and the losses to the boats that exit the industry.

Assuming an average pond size of 10m by 20m, owing to the high fixed cost and the scale-economics involved, the pond/tank culture is only profitable if at least 3 ponds/tanks are farmed. Fieldwork conducted by aquaculture experts demonstrates that the fixed costs of aquaculture equate to around GHS 6,700 per farm, with a variable cost per pond of GHS 6,800 (personal communication, aquaculture expert / consultant). To promote aquaculture, in addition to training the potential farmers and providing them access to land, the government should also give farmers interest-free credit as well as subsidized feed to enable them to break-even. This will amount to GHS 5,200 per tilapia pond for two years, given that the farmer begins with one pond/tank and only add an additional pond after two years. This brings the total expenditure to GHS 434 million per year for the first two years of which GHS 262 million is the cost paid by the farmers, GHS 101 million the subsidies paid by the government, GHS 66 million the compensation for displacement and GHS 5 million for extension.

In the third and fourth year of operation, the farmers expand to 2 ponds and can acquire loans at the going market rate, but feed must be subsidized. The total costs in these years are GHS 493 million of which GHS 388 million is the cost paid by the farmers, GHS 37 million the subsidies paid by the government for feed, GHS 66 million is the compensation for displacement and GHS 2 million for extension.

In years 5 and 6, farmers expand to 3 ponds and the total cost is GHS 585 million. Of this, GHS 66 million represents displacement costs, with the remainder costs paid by farmers save a small amount set aside for extension (GHS 2 million). In the remaining years modeled, the costs are GHS 714 million of which GHS 66 million represents displacement costs and the remainder, costs paid by aquaculture farmers.

The benefits comprise increased rents from marine fisheries due to lower effort and revenues from aquaculture. As discussed, the increased rents for remaining boats is GHS 107 million per year. For aquaculture, revenues per pond are estimated at GHS 5,600 (personal communication, MOFAD). At this level, aquaculture does not make a meaningful profit within the first for years. Total benefits in years 1 and 2 (one pond) are GHS 326 million of which 219 million is revenue from aquaculture. In years 3 and 4, when farmers have two ponds, the benefit is GHS 545 million with 437 million being the revenue from aquaculture.

In years 5 and 6 (three ponds) the benefit is GHS 763 million and in the remaining years (four ponds) GHS 982 million. By year six, the beneficiaries are making greater rents than they did in marine fishing.

In summary, restricting the number of artisanal canoes in order to maximize rents in the capture marine fisheries, while ensuring that displaced fishmen who lost their jobs are (theoretically) compensated for the lost rents due to the displacement, yields a benefit-cost ratio of 1.2 over a 10-year period, when a central social discount rate of 8% is applied. The provision is made for compensation because, without incentives, the fishermen may be reluctant to move to aquaculture. Ongoing fieldwork has revealed that the fishermen are more willing to shift to water-based alternative income generation activities compared to other activities including farming.

Table 2. Summary of Cost and Benefits of Limiting Fishing Effort and Supporting Aquaculture

Discount Rate	**Benefit (GHS million)**	**Cost (GHS million)**	**BCR**
5%	5,291	4,424	1.2
8%	4,465	3,786	1.2
14%	3,275	2,858	1.1

Planting Video Devices on Trawl Vessels

Industrial trawlers in Ghana are licensed to target demersal stocks within the Exclusive Economic Zone (EEZ) but outside of the Inshore Exclusive Zone (IEZ) where artisanal fishers operate. (Fisheries Act 625 of 2002). The number of trawlers currently operating within Ghanaian waters is 80, which is larger than the number of vessels corresponding to the MSY, 52. (MoFAD, 2015). Thus, akin to the artisanal fishery, the trawl fishing industry is overcapitalized, and the stocks are heavily overfished with potential rent losses amounting to 52% of the maximum profit which could be attained from the fishery (Akpalu et al., 2018). In addition to having too many vessels in the fishery, the trawlers illegally target small pelagic species, freeze them into pellets, and transship them to boats operated by middlemen who in turn retail them to fish processors in fishing communities along the coast. The illegal practice, which is commonly known as *saiko*, intensifies congestion externality in the marine capture fishery, accelerating depletion of pelagic stocks. When a pellet of *saiko* fish is defrosted, the quality of the fish is generally much lower than similar species landed directly by artisanal fishermen. Fish processors complain about being coerced by the *saiko* traders to buy such poor-quality fish. Repudiations are met with reprisals when fresh fish is landed by the canoe owners who also engage in *saiko* trading. Moreover, the fishing technique employed by the trawlers destroys the benthic floor of the ocean. In 2017, the saiko catch was estimated at 100,000 metric tons, which is about 57% of total artisanal catch for the year (EJF, 2019; EJF and Hen-Mpoano, 2019).

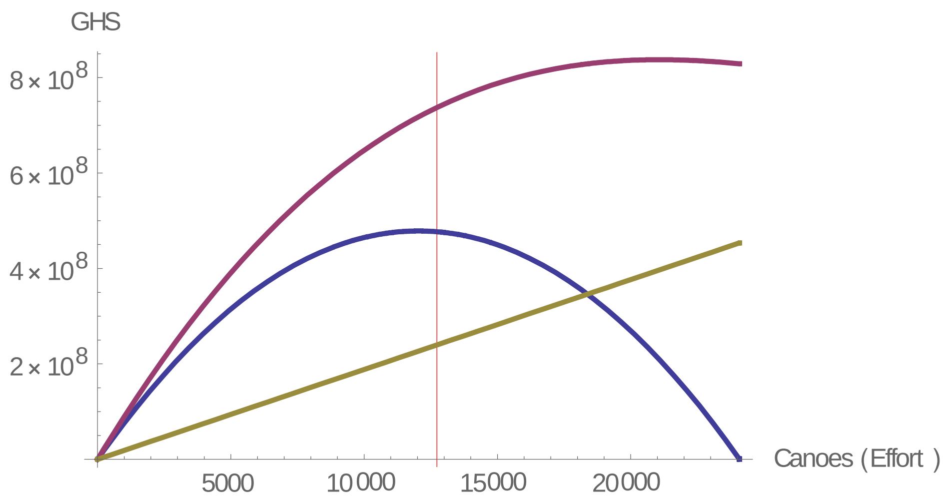
Following Akpalu and Vondolia (2013), a spatial bio-economic model has been employed to estimate the potential gain in rents if saiko ends, as a result of planting video devices on the trawl vessels so their activities can be monitored.

Costs and Benefits

Currently there are approximately 80 trawl vessels operating in the fishery. Suppose video equipment called 'FishEye of Trident' is installed on each vessel at an estimated total cost of GHS 10.8 million, including installation cost. Each vessel will be monitored by two individuals, who will be trained at the cost of GHS 5,400 per person. After the training, everyone will receive an annual salary of GHS 32,400. In addition, the annual maintenance cost of the equipment is estimated to GHS 5,540,000. Thus, the total cost of planting video devices on the trawl vessels is estimated at GHS 22.4 million in the first year and GHS 10.7 million per year thereafter. Over the period of analysis, the total costs are about GHS83million at an 8% discount rate.

With regards to the benefits associated with installing video devices on the trawlers, the spatial analysis assumes that the pelagic stocks outside of the IEZ will spill over inshore where they can be harvested by the artisanal fishers. Using the estimated parameter values employed in the earlier analyses and a dispersion parameter that indicates that a proportion of the stock in distant waters migrate to the management area of the artisanal fishers, Fig. 9 illustrates the potential gain due to the intervention, which is the gap between the blue and the pink curves along the vertical red line. The potential annual increase in profit is estimated to be approximately GHS 260 million. This is equal to a 72% increase in artisanal profits. Over the period of analysis, the total benefits are equal to about GHS1.75 billion at an 8% discount rate.

Fig. 9. The Effect of Installing Video Devices on Trawlers on Rent



In summary, a relatively small one-off cost of GHS 11.7 million with ongoing (recurrent) costs of GHS 10.7 million on maintenance and wages/salaries would be enough to install and monitor cameras on 80 trawler vessels currently operating in Ghana. Since the *saiko* fish is an inferior fish protein, halting such an illegal fishing activity is unlikely to impact the price of fish and the consumer surplus from fish consumption. The associated annual benefit is GHS260.3billion, yielding a BCR of 21.1 at an 8% discount rate. This calculation rests on a key assumption that surveillance works, insofar as installing the video devices will lead to curtailing illegal fishing. Additionally, since the *saiko* fish is of poor quality, the GHS 260 million is considered an efficiency gain, rather than a mere transfer from trawlers to artisanal fishers.

Table 1. Summary of Costs and Benefits of Planting Video Devices on Trawlers

Discount Rate	**Benefit (GHS million)**	**Cost (GHS million)**	**BCR (GHS million)**
5%	2,010	94	21.4
8%	1,747	83	21.1
14%	1,358	66	20.5

Concluding Remarks

The artisanal marine fish stock in Ghana is biologically overexploited, with a corresponding 37% potential annual rent loss. This is probably due to the mismanagement of the fishery resource as a common pool leading to congestion externalities and reduced aggregate profits compared to the maximum economic yield (MEY). In addition, the illegal fishing of small pelagic stocks by trawl vessels further dissipates rents and intensifies the race to the bottom. Three intervention proposed to address the problem are replacement of illegal/destructive fishing nets, limiting fishing effort while providing training and subsidizing feed for aquaculture, and installing video devices in the trawl vessels. These interventions are necessary and can prevent the stock from imminent collapse. The short-term political cost of implementing these interventions may be significant, but medium to long term social benefits are obvious and greatly outweigh the former. As noted earlier, compared to the effect of artisanal fishery management failures, the impact of the activities of trawl vessels on artisanal stocks has far more serious implications for food security and sustainable livelihoods within and beyond the fishing communities in Ghana. It is therefore evident that the returns from halting their illegal catch of small pelagic species by the trawl vessels generate by far the highest value for money. This is followed by the replacement of nets with small mesh sizes.

The primary limitation of this analysis is that the results assume each intervention works as intended i.e. that legal nets will be used, that fishermen will move to aquaculture given the right guidance and incentives and, that surveillance will lead to legal fishing behavior by trawlers. If reality deviates from this ideal then the actual BCRs will be lower than that reported. Unfortunately, there is a dearth of studies that robustly estimate the impact of fisheries management strategies, for example via randomized control trials. That said, this challenge is present for all interventions, and as such, the rank order of the results is likely to be correct. Additionally, a recent comprehensive study covering half the world's fish landings demonstrated correlation between fisheries management intensity and rising fish stocks, suggestive that management strategies are on average working as intended (Hilborn et al. 2020).

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Appendix A

Table A1: OLS Estimation of Yield Function for Artisanal Fisheries in Ghana (1986-2016)

Variables	**Coefficients**
Effort (# of boats)	35.1596***
	(4.134)
Effort-squared	-0.00146***
	(0.00036)
Prob > F	0.0000

Source: Data was obtained from Fisheries Scientific Survey Division (1973-2016)

Table A2: Calculating the MSY, MEY and The Corresponding Effort Levels for Artisanal Fisheries in Ghana

Parameters & Variables	**Values**
α ; β	35.1596; 0.00146
r	1.052
$q = {}^{\beta r}\!/_{\alpha}$	0.00004368
$k = {}^{\alpha}\!/_{q}$	804857.982
c	18834
p	2261
$E_{msy} = {}^{r}\!/_{2q}$	12041
$MSY = \frac{rk}{4}$	211,678
$E_{mey} = \frac{r}{2q}\left(1 - \frac{c}{pqk}\right)$	9188
MEY	199,796

Table A4. Data on Catch and Fishing Effort (# of Canoes) in Ghana (1986-2016)

Year	Catch (total)	Canoes	Catch per Canoe
1986	190196.5	8214	23.16
1987	261451.3	8214	31.83
1988	244042.2	8160	29.91
1989	220877.7	8052	27.43
1990	242020.1	8264	29.29
1991	215847.1	8476	25.47
1992	307931.2	8688	35.44
1993	257237.4	8672	29.66
1994	211746.8	8657	24.46
1995	210659.3	8641	24.38
1996	298249.0	8626	34.58
1997	215125.4	8610	24.99
1998	189458.6	8953	21.16
1999	164829.0	9296	17.73
2000	275964.7	9638	28.63
2001	236355.3	9981	23.68
2002	200769.2	10392	19.32
2003	238796.3	10802	22.11
2004	267909.8	11213	23.89
2005	218871.9	11381	19.23
2006	231680.6	11550	20.06
2007	187088.1	11718	15.97
2008	254133.46	11886	21.38
2009	226755.28	12055	18.81
2010	198152	12223	16.21
2011	197663.26	12391	15.95
2012	189246.09	12560	15.07
2013	178219.017	12728	14.00
2014	176165.488	12346	14.27
2015	187414.393	11965	15.66
2016	179721.312	11583	15.52

The Ghanaian economy has been growing swiftly, with remarkable GDP growth higher than five per cent for two years running. This robust growth means added pressure from special interest groups who demand more public spending on certain projects. But like every country, Ghana lacks the money to do everything that citizens would like. It has to prioritise between many worthy opportunities. What if economic science and data could cut through the noise from interest groups, and help the allocation of additional money, to improve the budgeting process and ensure that each cedi can do even more for Ghana? With limited resources and time, it is crucial that focus is informed by what will do the most good for each cedi spent. The Ghana Priorities project will work with stakeholders across the country to find, analyze, rank and disseminate the best solutions for the country.

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