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Optimum fisheries management under climate variability

Evidence from artisanal marine fishing in Ghana

Wisdom Akpalu[1], Isaac Dasmani[2],
and Ametefee K. Normanyo[3]

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Abstract

In most coastal developing countries, the artisanal fisheries sector is managed as a common pool resource. As a result, such fisheries are overcapitalized and overfished. In Ghana, in addition to anthropogenic factors, there is evidence of rising coastal temperature and its variance, which could impact the environmental carrying capacity of the fish stock. This study investigates the effect of climate variation on biophysical parameters and yields. Our results indicate that the rising temperature is decreasing the carrying capacity. As a result, an optimum tax on harvest must reflect climate variability, as well as the congestion externality.

Keywords: climate variability, optimal tax, generalized maximum entropy, Ghana
JEL classification: Q22, H21, C61

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[1]State University of New York and Center for Environmental Economics Research & Consultancy (CEERAC), corresponding author, email: wakpalu@yahoo.com; [2]University of Cape Coast, Ghana and CEERAC; [3]Ho Polytechnic, Ghana and CEERAC.

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UNU World Institute for Development Economics Research (UNU-WIDER)
Katajanokanlaituri 6 B, 00160 Helsinki, Finland

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1 Introduction

In spite of the plethora of policies aimed at sustaining capture fish stocks around the world, evidence abounds that most stocks are heavily overexploited (Pauly and Zeller 2003; OECD 2006; FAO 2007). In a recent World Bank study entitled 'The Sunken Billions', it has been found that a number of fisheries have completely collapsed or are on the verge of doing so (Arnason et al. 2009). 50 per cent of capture fish stocks are considered fully exploited; 25 per cent are overexploited, depleted, or recovering from depletion, and are yielding less than their maximum sustainable yield; and the remaining 25 per cent are underexploited or moderately exploited (Arnason et al. 2009). In coastal developing countries where fishery sectors directly employ significant numbers of people and regulations are generally inadequate, food security and sustainable livelihoods are directly threatened (Pauly and Zeller 2003; Arnason et al. 2009). In Sub-Saharan Africa, for example, the fisheries sector directly employs close to 3 million people and additional 7.5 million people are engaged in fish processing and trading. Also, it is estimated that in Africa the current annual revenue from capture fishery (US$2 billion) generates a multiplier effect of 2.5 times (US$5 billion) through trickle-up linkages (Chimatiro 2010). The high number of fishers in coastal developing countries is due to a growing poverty trap.

In Ghana, artisanal and semi-industrial fishing are the most important direct and indirect employment generating activities within the entire coastal zone. The artisanal sector supports about 1.5 million people and lands about 70-80 per cent of total marine catches (Bannerman et al. 2001). The artisanal and semi-industrial fisheries are managed as unregulated common pool resources (CPR), hence are overcapitalized resulting in biological overfishing (i.e., declining catch per unit effort). The existing regulations include ban on the use of light aggregation equipment (which involves shinning light in the ocean, when the moon is out, to attract fish and increase harvest); ban on the use of mesh sizes smaller than an inch in stretch diagonal; and ban on the use of explosives in fishing. These regulations aim at limiting fishing efforts which is on the rise. For example, after a sharp increase in artisanal catch per unit effort between 1989 and 1992, it declined from 1992 through 2008 although fishing techniques improved and the number of crew per boat also increased. Within the same period, available data shows the annual coastal temperature and its variance has been on the rise. Since pelagic stocks targeted by artisanal fishers feed on planktons that depend on seasonal upwelling, it is likely that, the rising coastal temperature is impacting catch per unit effort. Although, favourable upwelling can increase with global warming, the rising temperature could impact other environmental conditions for spawning, recruitment, or larval development, among others (Bakun 1990; Allison et al. 2005).

To reduce fish catches to sustainable levels, an optimum market-based policy instrument such as a tax on cost per unit effort or harvest is necessary. However, the efficacy of such a policy instrument hinges on the knowledge of the biophysical dynamics of the stocks. Two recent studies have shown that a fish stock could be potentially depleted if the biodynamic is misperceived, even if catch policies exist (Sterner 2007; Akpalu 2009). Using time series data on artisanal marine fishing in Ghana (1972-2007), this study extends the existing surplus production function to account for the impact of changes in atmospheric temperature and its variance on the environmental carrying capacity of artisanal fish stock; estimate the biophysical parameters employing the generalized maximum entropy (GME) estimators, which addresses the classical linear regression problems of endogeneity, multi-collinearity, and limited observations; estimate the optimum tax necessary to internalize congestion externality and the climate impact on fish yield; and forecast the local atmospheric temperature as well as discuss its implication for the optimum tax. The results showed that the rising temperature yields negative biological response by decreasing the carrying capacity. In addition, a univariate analysis of the annual coastal temperature indicated that it will continue to rise at least in the near future. As a result, the tax rate must be set high enough to account for the increasing temperature in order to protect the artisanal fish stock.

The remainder of the paper is organized as follows. Section 2 presents the optimal control model for the optimal tax, and this is followed by incorporating the atmospheric forcing in the surplus production function in Section 3. Section 4 contains the empirical model and discussion on the estimation method. Section 5 provides the preliminary results and the final section; Section 6, concludes the paper.

2 The model for optimum tax

To briefly outline the model for obtaining the optimum tax, following Akpalu (2013), suppose a fishery is managed as a CPR. Let the biomass (x) of the fish stock grow according to a logistic function $g(x,K)$, where K is a constant environmental carrying capacity $g_x(.)>0$ and $g_{xx}(.)\le 0$. For analytical convenience let the logistic growth function be $g(x,K)=rx\left(1-\frac{x}{K}\right)$, where r is intrinsic growth rate. Furthermore, let $c(x)$ and p be cost per unit harvest and price per kg of fish, respectively. In addition, assume future benefits and costs are discounted at a positive rate, δ. The value function of the entire fishery is given by Equation (1) and the stock dynamic Equation is (2).

$$V(x,H)=\max_{H}\int_{0}^{\infty}\left(pH-c(x)H\right)e^{-\delta t}dt \tag{1}$$

$$\dot{x}=rx\left(1-\frac{x}{K}\right)-H \quad \text{, with} \quad H=\sum_{i=1}^{n}h_i \tag{2}$$

where $\dot{x}=\frac{dx}{dt}$, H is aggregate harvest, and h_i is the harvest of one economic agent (i). The corresponding current value Hamiltonian of the programme is

$$\Gamma(x,H,\mu)=\left(pH-c(x)H\right)+\mu\left(rx\left(1-\frac{x}{K}\right)-H\right) \tag{3}$$

From the maximum principle, assuming an interior solution exists, the first order condition with respect to harvest (H) is

$$\frac{\partial\Gamma(.)}{\partial H}=p-c(x)-\mu=0 \tag{4}$$

Equation (4) simply stipulates that in an inter-temporal equilibrium harvest must be at a level that equates net marginal benefit (i.e., $p-c(x)$) to the scarcity value of the stock (i.e., μ). If $p-c(x)>\mu$, harvest has to be at its maximum. On the other hand it must be set to zero, if $p-c(x)<\mu$. The corresponding costate equation is

$$\dot{\mu} - \delta\mu = -\frac{\partial H(.)}{\partial x} = c_x H - \mu r\left(1 - \frac{2x}{K}\right) \tag{5}$$

Equation (5) implies that, in dynamic equilibrium, the interest earnable on the net marginal benefit from harvesting one kilogram of fish today (i.e., $\delta\mu$) must equate the sum of the capital gain from conserving that kilogram of fish (i.e., $\dot{\mu}$) and some stock effect (i.e., $-c_x H + \mu r\left(1 - 2xK^{-1}\right)$). In steady state $\dot{x} = \dot{\mu} = 0$ so that (4) and (5) become

$$p - c(x) = \frac{-c_x\left(rx\left(1 - \frac{x}{K}\right)\right)}{\delta - r\left(1 - \frac{2x}{K}\right)} \tag{6}$$

Now suppose the stock is harvested as a CPR by n users. Following Maler et al. (2003) and Akpalu (2013), the optimization programme for each community is

$$V(x, h_i) = \max_{h_i} \int_0^\infty \left(p - c(x)\right) h_i e^{-\delta t} dt, \quad i = 1, 2, ..., n \tag{7}$$

$$\dot{x} = rx\left(1 - \frac{x}{K}\right) - \sum_i^n h_i, \quad H = \sum_i^n h_i \tag{8}$$

The corresponding first order condition from the maximum principle is

$$\frac{\partial Z(.)}{\partial h_i} = p - c(x) - \mu_i = 0, \quad i = 1, 2, ..., n \tag{9}$$

The shadow value assigned to the resource by each symmetric community is $\mu_i = \frac{\mu}{n}$. The symmetric open-loop Nash equilibrium solution is

$$p - c(x) = \frac{\mu}{n} = \frac{-c_x\left(rx\left(1 - \frac{x}{K}\right)\right)}{n\left(\delta - r\left(1 - \frac{2x}{K}\right)\right)} \tag{10}$$

Equation (10) could be solved for the equilibrium stock level (i.e., $x^{**} = x(K, n)$). Suppose the resource is harvested as a CPR and let a tax be imposed on cost of harvest (i.e., $c(x)\left(1 + \tau\right)$) to generate a first best solution. The equilibrium stock equation with the tax is

$$p - c(x)\left(1 + \tau\right) = \frac{-c_x\left(1 + \tau\right)\left(rx\left(1 - \frac{x}{K}\right)\right)}{n\left(\delta - r\left(1 - \frac{2x}{K}\right)\right)} \tag{11}$$

or

$$\frac{n\left(p-c(x)(1+\tau)\right)}{(1+\tau)}=\frac{-c_{x}\left(rx\left(1-\frac{x}{K}\right)\right)}{\left(\delta-r\left(1-\frac{2x}{K}\right)\right)}$$

From Equation (6) and (11): $\frac{n\left(p-c(x^{*})(1+\tau)\right)}{(1+\tau)}=p-c(x^{*})$, which implies

$$tax(\tau)=\frac{p-c\left(x^{*}\right)}{p/(n-1)+c\left(x^{*}\right)} \tag{12}$$

If $n>1$, aggregate catch will exceed the socially desirable level and a policy intervention will be required to regulate catch. Using $c(x^{*})=\frac{c}{qx^{*}}$ (where c and q are cost per unit effort and catchability coefficient, respectively), the steady state stock x^{*} is

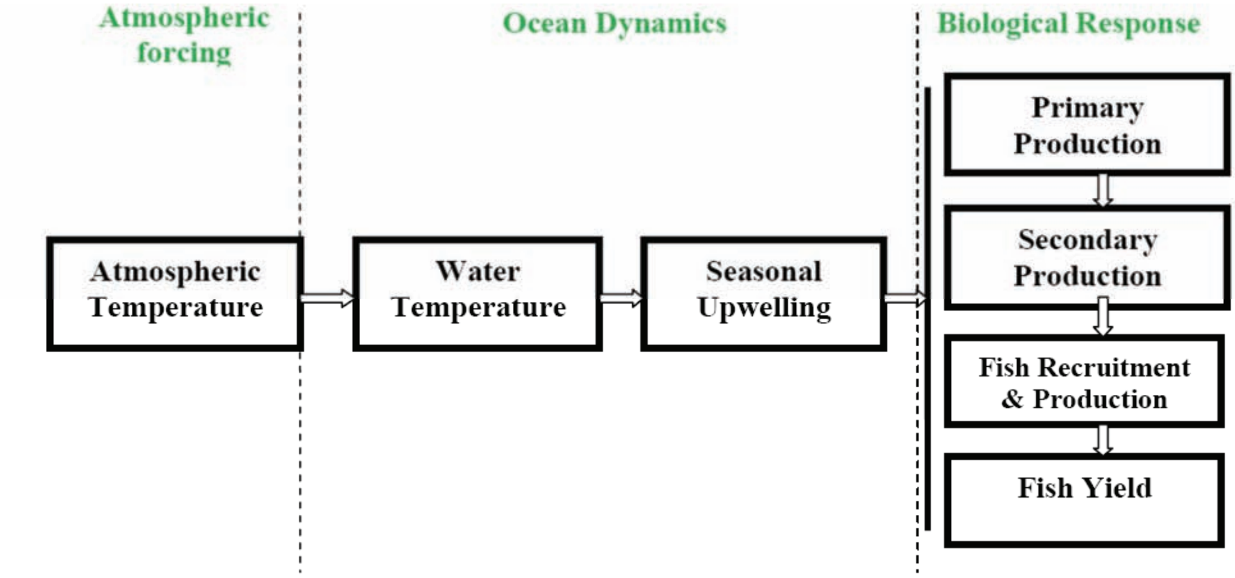
$$x^{*}=\frac{k}{4}\left[\left(\frac{c}{pqk}+1-\frac{\delta}{r}\right)+\sqrt{\left(\left(\frac{c}{pqk}+1-\frac{\delta}{r}\right)^{2}+\frac{8c\delta}{pqkr}\right)}\right] \tag{13}$$

The specific tax expression is based on these specific functional forms. The tax depends on the values of the socio-economic parameters (i.e., p, c and δ), which are readily available, and biological parameters (i.e., r, q and k) which are not.

Climate variability and optimal tax rate

If climate variability impacts the carrying capacity, then the tax rate must reflect potential variability in the climate. As indicated in the introduction, there is overwhelming evidence that climate variability may impact carrying capacity of the stock. Atmospheric forcing may result in a change in atmospheric temperature (see Figure 1). The change in temperature impacts water temperature and subsequently influences seasonal upwelling (or downwelling). This influences primary production, species distribution, fish yield, and increased variability of catches (Allison et al. 2005).

Figure 1: The flow chart of the impact of atmospheric temperature on fish yield



Source: authors' compilation.

To account for the impact of atmospheric temperature on fish production, we surmise that the carrying capacity is defined as

$$k = \frac{k_0}{1+\varepsilon\Delta T_t + \eta\sigma_t} \tag{14}$$

Where T and σ are the state of the climate variable and its variances, respectively; Δ is notation for first difference[1]; and k_0, ε, and η are constants. The corresponding optimum path of the stock is

$$x^*(t) = \frac{k_0}{4(1+\varepsilon\Delta T_t+\eta\sigma_t)}\left[\left(\frac{c(1+\varepsilon\Delta T_t+\eta\sigma_t)}{pqk_0}+1-\frac{\delta}{r}\right)+\sqrt{\left(\left(\frac{c(1+\varepsilon\Delta T_t+\eta\sigma_t)}{pqk_0}+1-\frac{\delta}{r}\right)^2+\frac{8c\delta(1+\varepsilon\Delta T_t+\eta\sigma_t)}{pqk_0 r}\right)}\right] \tag{15}$$

3 Obtaining the biophysical parameters

To establish the link between climate variability and fish production, a biological model is employed. In order to estimate the biological parameters, a number of authors have employed models by Schaefer and Fox (see e.g., Clarke et al. 1992). These models assume equilibrium or steady state conditions in order to obtain an equation that is used to estimate next period's catch per unit effort without specifying future anticipated effort (Clarke et al. 1992). However, Schnute (1977) has shown that these models may be invalid for non-equilibrium conditions and the assumption that catch per unit effort could be predicted without specifying

1 We used the change in temperature because the levels of the series are within a limited range, given the period considered for the empirical analysis. As expected, the levels were not significant in the empirical analysis (presented in the later section of the paper) but the first differences were.

future anticipated effort contradicts almost all theory on fisheries biology. As a result, the author suggested a modified version, which is Equation (16)

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = r - \frac{r}{qk_0}\left(\frac{U_t + U_{t+1}}{2}\right) - q\left(\frac{E_t + E_{t+1}}{2}\right) \tag{16}$$

where $U_t = \left(\frac{h_t}{E_t}\right)$ signifies catch per unit effort, and E_t is fishing effort. As indicated in the introduction, there is overwhelming evidence that climate variability may impact carrying capacity of fish stock. Using Equation (14) in (16), gives

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = r - \frac{r}{qk_0}\left(\frac{U_t + U_{t+1}}{2}\right) + \frac{r\varepsilon}{qk_0}\left(\frac{U_t + U_{t+1}}{2}\right)\Delta T_t + \frac{r\eta}{qk_0}\left(\frac{U_t + U_{t+1}}{2}\right)\sigma_t - q\left(\frac{E_t + E_{t+1}}{2}\right) \tag{17}$$

4 The empirical model and estimation methods

In this section the extended Schnute model (i.e., Equation 17) and an estimation method known as GME estimator is presented. For the purpose of estimation, Equation (17) is specified as

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = a_0 + a_1\bar{U}_t + a_2\bar{U}_t\Delta T_t + a_3\bar{U}_t\sigma_t + a_4\bar{E}_t + \mu_t \tag{18}$$

where $\bar{U}_t = \left(\frac{U_t + U_{t+1}}{2}\right)$, $\bar{E}_t = \left(\frac{E_t + E_{t+1}}{2}\right)$, $a_0 = r > 0$, $a_1 = -\frac{r}{\sigma k} < 0$, $a_4 = -q < 0$, and μ_t is an error term. Time series data on catch, fishing effort, and temperature is required to estimate Equation (18).

4.1 Empirical estimations: generalized maximum entropy

The obvious problem with applying ordinary least squares estimation procedure to Equation (18) is endogeneity since the dependent variable interacts with other variables on the right hand side. It is also very likely that some of the variables are highly correlated. As a result, the coefficients are estimated using GME, which are explained in the subsequent sections. The GME method could generate reliable estimates of the parameters of our model. The GME is a semi-parametric estimator and belongs to a class of estimators used in engineering and physics. To present the GME estimator, let

$$a_k = \sum_s z_{ks} p_{ks} \tag{19}$$

where $p_{ks} \geq 0$ are unknown probabilities and $\sum_s p_{ks} = 1$; z_{ks} constitutes a predetermined discrete support space (s) for the parameters; and a_k is as defined in Equation (18). Furthermore define the error term in Equation (18) as

$$u_i = \sum_g V_{ig} w_{ig} \tag{20}$$

where $w_{ig} \geq 0$ are unknown probabilities and $\sum_g w_{ig} = 1$; V_{ig} constitutes an a priori discrete support space (g) for the errors; and u_i is as defined in Equation (18). The GME estimator is specified as

$$\max\ H(p_{ks}, w_{ig}) = -\sum_s p_{ks} \ln(p_{ks}) - \sum_g w_{ig} \ln(w_{ig}) \tag{21}$$

subject to Equation (18), but with the coefficients and the error term substituted by Equations (19) and (20). The limitation of this method is that the values of the parameters are sensitive to arbitrarily chosen support values making policy recommendations sensitive to such values. The estimations are implemented in general algebraic modelling system (GAMS).

4.2 Data types and sources

Data on catch and effort were collected from the Directorate of Fisheries of the Ministry of Food and Agriculture (MOFA) in Ghana. The Directorate is mandated to carry out research for the assessment for fisheries resources. As noted in the introduction, the artisanal fishery sector is one of the most important sectors within the economy. However, recent landing statistics for the artisanal fleet indicate landings peaked in 1992, and then declined due to overexploitation (Koranteng 1998). The data on temperature was collected from Ghana Meteorological Agency. The summary statistics of the data is presented in Table 1.

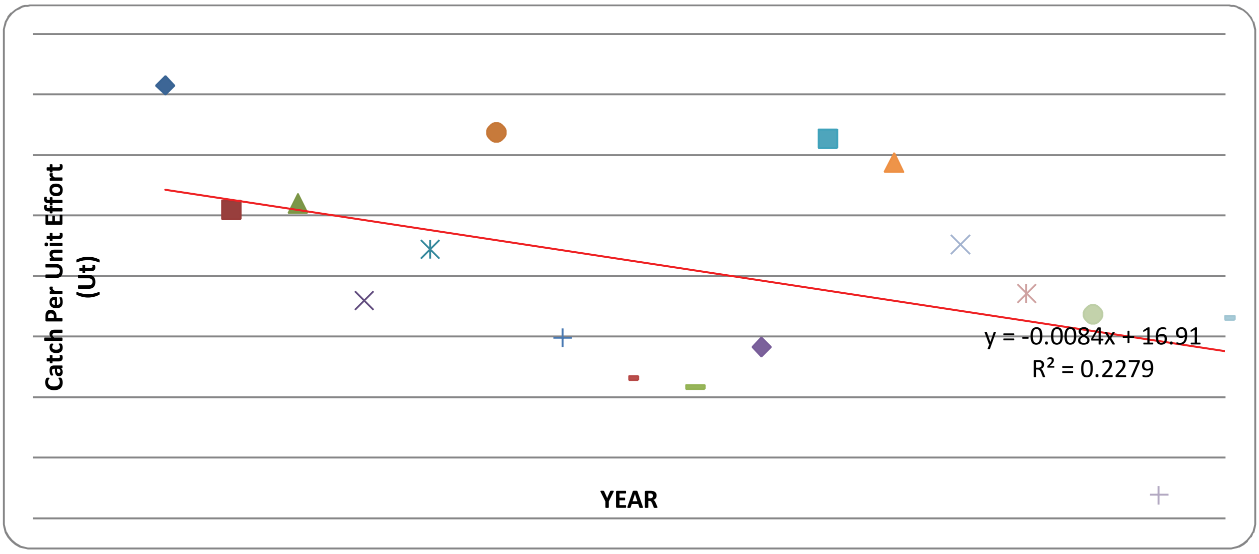
Table 1: Descriptive statistics of catch, fishing trips and coastal temperature in Ghana

Variable	1972-2007		1990-2007	
	Mean	Standard dev.	Mean	Standard dev.
Catch (in kg)	195353.8	53378.27	229212.1	34190.69
Effort (# of trips)	1319614	1549476	1653440	1988563
Temperature (in ^{0}C)	27.04324	0.4193518	27.31579	0.291096
Std Dev. of temperature	1.193149	0.1699718	1.192671	0.124451

Source: Catch and effort data is collected from the Directorate of Fisheries, Ghana; and temperature data collected from Ghana's Meteorological Agency.

From Table 1, both catch and effort levels have increased over the last 18 years. In addition, as depicted in Figure 2, catch per unit effort has also declined, on the average, from 1992 through 2008.

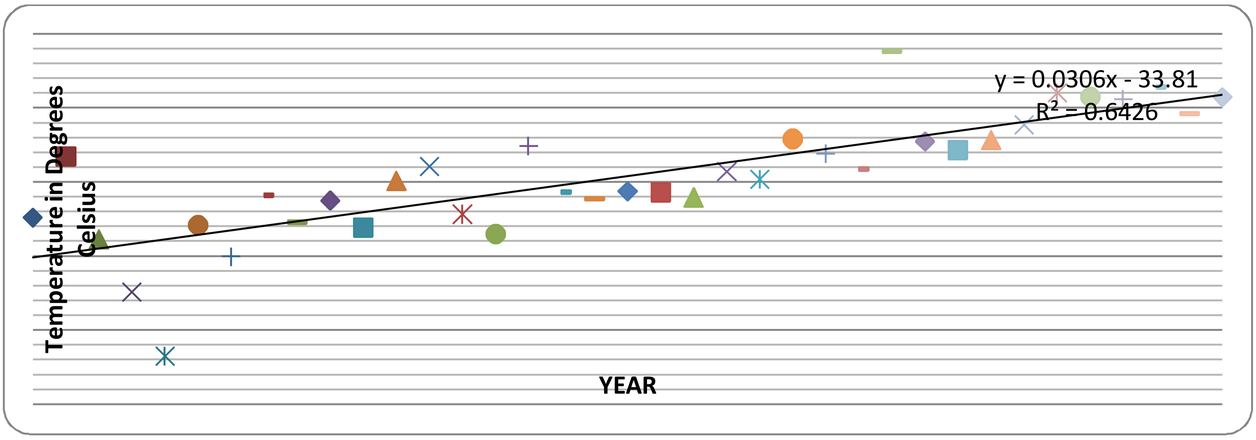
Figure 2: Trends in catch per unit effort of artisanal stocks (1992-2008)



Source: authors' illustration.

Furthermore, from Table 1, the mean temperature within the entire period (1972-2007) is lower than that of the last 18 years (1990-2007). The time trend of the atmospheric coastal temperature has revealed a rising trend over time (see Figure 3). Moreover, although the annual variance of the coastal temperature (shown in Figure 4a)[2] depicts a stationary process, a careful examination reveals an upward trend beginning 1990 through 2008 (shown in Figure 4b); a period coinciding with the decline in the catch per unit effort.

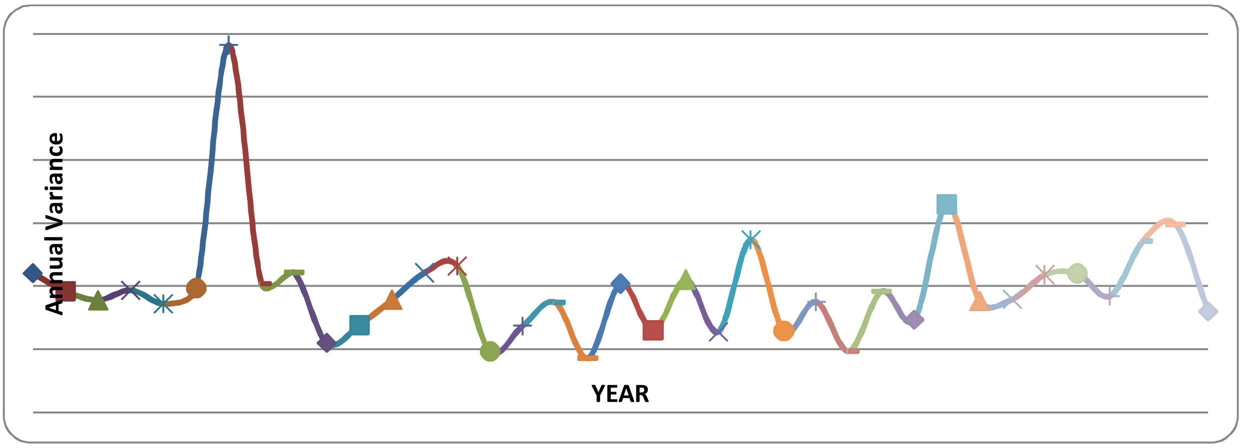
Figure 3: Trends in coastal temperature (1972-2008)



Source: authors' illustration.

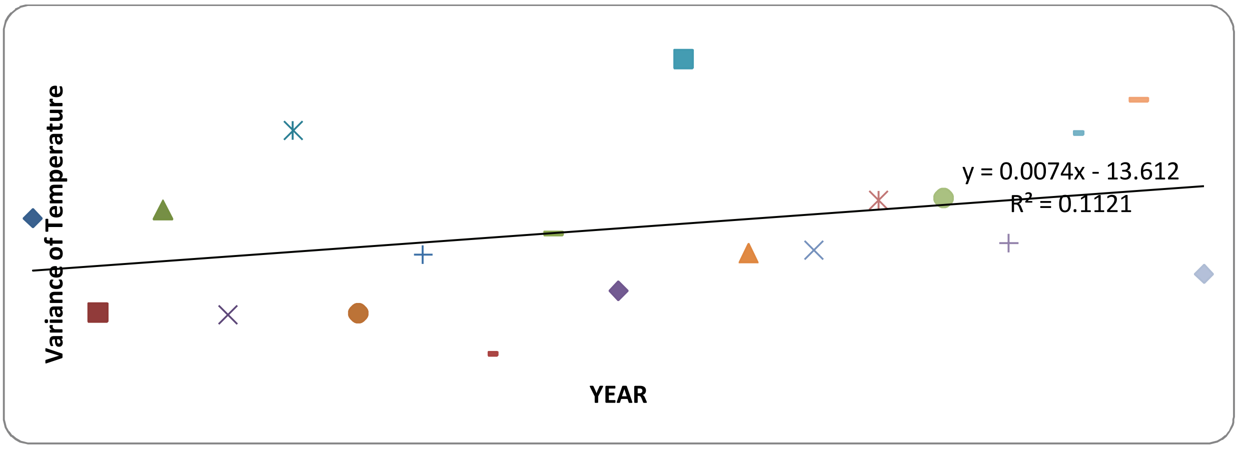
[2] The variance is calculated as the sum of the squared deviation of monthly temperature from the yearly average, divided by 11 (i.e., degrees of freedom).

Figure 4a: Trends in the variance of coastal temperature (1972-2008)



Source: authors' illustration.

Figure 4b**:** Trends in the variance of coastal temperature (1990-2008)



Source: authors' illustration.

5 Results

The biological parameters were estimated using GAMS. Since the catch intensified beginning 1990, the data for the estimation spans a period of 1990-2007. For the purpose of comparison, two versions of the model were estimated: one without the climate variables and a complete version with the climate impact on carrying capacity. The results of the estimation are reported in Table 2.

Table 2: Estimated biological parameters of the Schnute equation

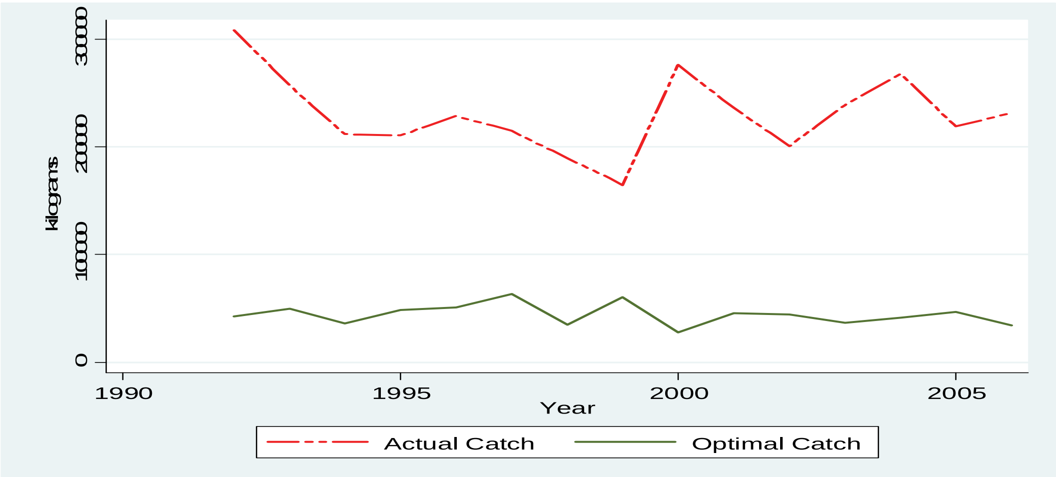
Parameters		Estimates	
Description	Notation	GME	
		1	2
Intrinsic growth rate	r	1.914	1.960
Catchability coefficient[3]	q	0.627x10^{-6}	0.636x10^{-6}
Carrying capacity (in kg)	k_0	530,066	449,683
Impact of temperature on k	ε		1.139
Impact of temperature variation on k	η		0.792
Pseudo R-squared		0.70	0.73

Source: authors' computations.

The pseudo R-squared indicates that including climate variables (i.e., the change in temperature and the annual variance of the temperature) in the model improves the fit of the estimation. Approximately 73 per cent of the variability in the dependent variables is explained by the regressors if the climate variables are considered. The corresponding value is 70 per cent if the climate variables are ignored. The environmental carrying capacity (k_0) indicates that, without accounting for climate impact, the maximum stock the environment could accommodate is approximately 450 tons. Furthermore, the values of the parameters ε and η are positive implying change in temperature and annual variance of temperature impact negatively on the carrying capacity (as per Equation 14).

Using the estimates for the biological parameters, a social discount rate (δ) of 3 per cent, an average price of US$264 taken from Akpalu and Vondolia (2012), and price to cost per unit effort ratio of 0.11 (or the average cost of harvest of US$232), the optimal catch series has been calculated. Figure 5 provides the plots of actual and estimated optimal catches. As clearly depicted by the graphs, the actual catches are much higher than the optimal values indicating a policy instrument is necessary to regulate catch. In addition, ignoring the climate impact may results in overestimation of the stock level as depicted in Figure 6.

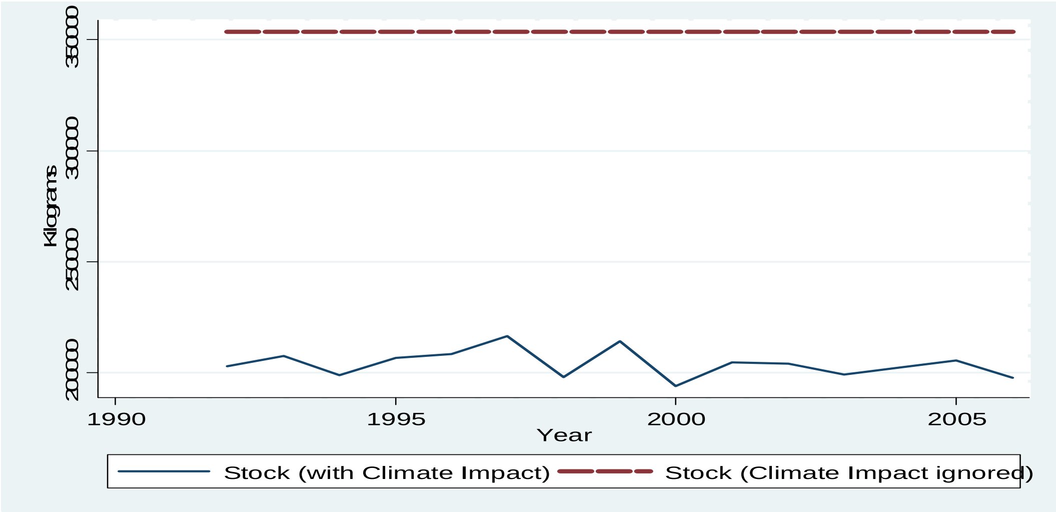
Figure 5: Actual and optimal catches of artisanal stocks in Ghana



Source: authors' illustration.

[3] Using surplus production functions, Clarke et al. (1992) estimated the catchability coefficient to be within the range of 0.376x10^{-6} and 0.913x10^{-6}.

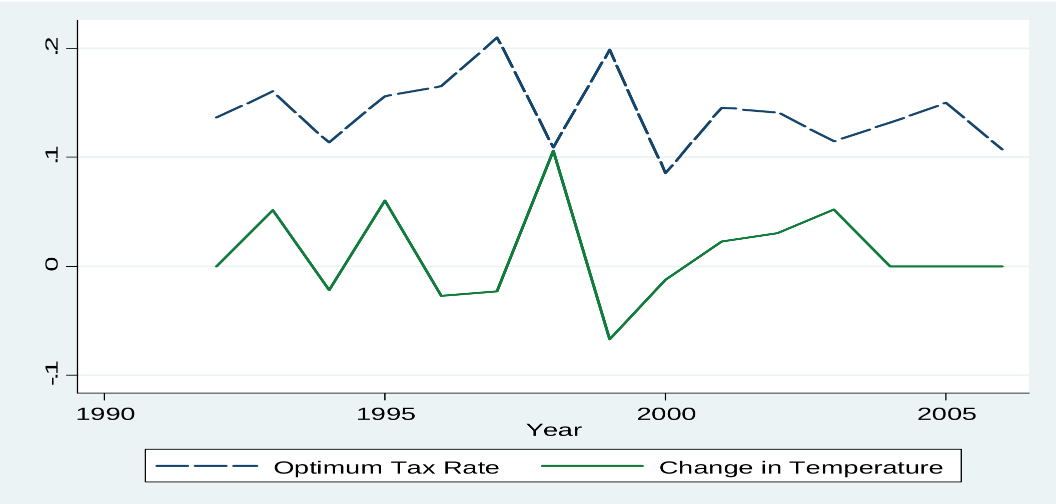
Figure 6: Misperceived stock due to ignorance of climate impact in Ghana



Source: authors' illustration.

The optimal tax path based on Equation (12) has also been calculated. Based on the values for price and cost per unit effort used, the values range from 8.5 per cent to 21 per cent, with the mean tax being 14.2 per cent. The implication is that for harvest levels to mimic the desired or optimal trajectory in Figure 5, the tax rate on cost of harvest must follow the series depicted in Figure 7. Currently premix fuel, which constitutes a significant input in production, is subsidized at an approximate rate of 18 per cent. Withdrawing the subsidy is necessary to lower catches to sustainable levels. Furthermore, the figure shows a direct relationship between the tax rate and the change in temperature. This makes sense because the carrying capacity decreases as the change in temperature increases leading to lower fish production. As a result the tax rate must increase to regulate harvest.

Figure 7: Optimum tax rates and change in annual temperature



Source: authors' illustration.

Predicting the coastal temperature

In the preceding section, it has been shown that if the coastal temperature increases at an increasing rate or its annual variance increases, the environmental carrying capacity will decrease causing fish production to decline. As a result, we proceeded to investigate whether or not the local coastal temperature and the variance will rise or fall in the near future based on the historical trends of the series. To forecast the future values, the time series properties of the data were investigated. Table 3 contains the results of the augmented Dickey-Fuller (ADF) tests. The results indicate that if trends and constants are included in the tests, the temperature series is stationary, but its annual variance is non-stationary at a 1 and 5 per cent significance level. The first difference of the variance is, however, stationary implying the temperature and variance are integrated of order zero and one respectively.

Table 3: Unit root analysis of annual temperature and variance of annual temperature

Series	ADF (with drift term and trend)			
	Z-Score	Critical values		
		1%	5%	10%
Temperature (Temp)	-5.455	-4.297	-3.564	-3.218
Variance of temperature (Vtemp)	-3.478	-4.297	-3.564	-3.218
First difference of Vtemp (DVtemp)	-5.455	-4.306	-3.568	-3.221

Source: authors' computations.

Following the Box-Jenkings approach to univariate time series econometric modelling, the plots of the autocorrelation and partial autocorrelation functions depict that the temperature series follow an autoregressive moving average (ARMA) process. A further analysis reveals that the variable could be modeled as ARMA (1, 10) process. The estimated results are presented in Table 5. The Wald Chi-square test indicates that the line is a good fit at a 1 per cent significance level. The coefficients of the first lag of the series, and the first and tenth lags of the error term are all significant at a 1 per cent level. In addition the drift term, denoting the average temperature, is 27.15 ºC and it is also significant at a 1 per cent level.

Table 4: Fitting temperature with ARMA

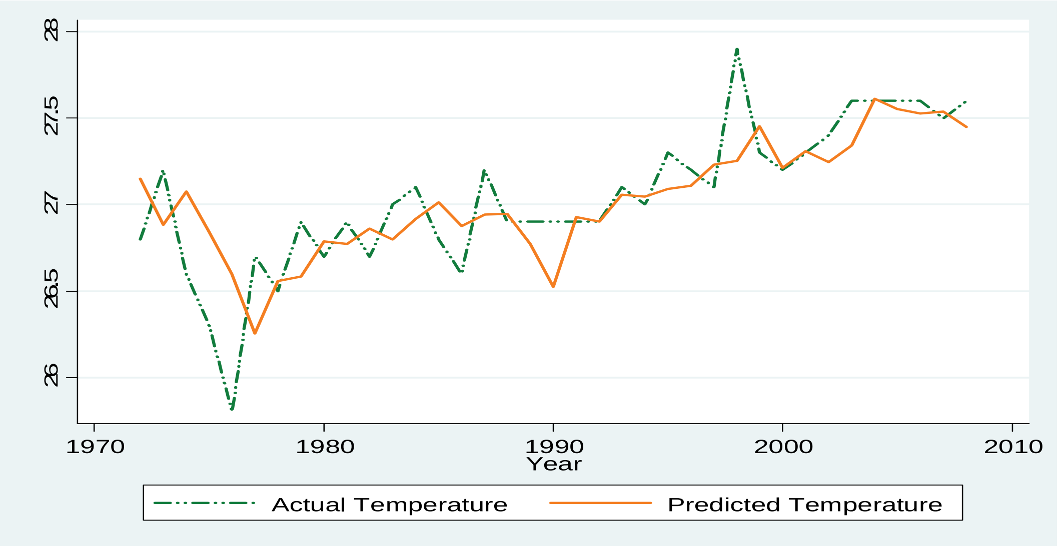
Variables	Coefficient
$Temp_{t-1}$	0.90 (0.048)***
e_{t-1}	-0.56 (0.18)***
e_{t-10}	0.55 (0.21)***
Constant	27.15 (0.28)***
Wald chi2(2)	345.53(Prob > 0.00)

Note: Standard errors are in parentheses; *** significant at 1%.

Source: authors' computations.

Based on the results of the univariate analysis, the values of the temperature are forecasted and the forecast and actual values are presented in Figure 8. From the figure, it is evident that the annual temperature will continue to rise in the near future. This also implies that the artisanal stock is likely to decline; hence higher taxes on cost of harvest may be necessary to protect the stock.

Figure 8: Actual and predicted values of atmospheric temperature



Source: authors' illustration.

Finally, the time path of the variance of the annual temperature is modelled. The corellogram of the first difference of the variance indicates it is an autoregressive (AR) (1) process without a drift term (see Table 5). The Wald Chi-square test indicates that the line is a good fit at a 99 per cent confidence level. The coefficient of the AR (1) term is negative indicating the first difference of the temperature is declining over time, with a marginal effect of -0.055. This also implies that the variance of annual temperature rises but at a decreasing rate. The plot of the actual and predicted values of the series in Figure 9 shows that the estimated model predicts the actual values quite well.

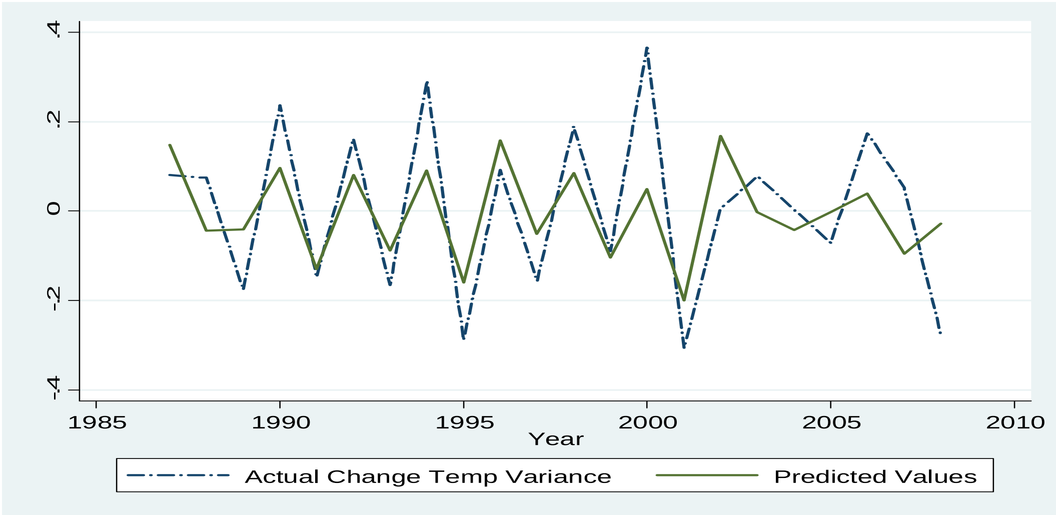
Table 5: Fitting change in variance of annual temperature with ARMA (1, 0)

Variables	Coefficient
$\Delta VTemp_{t-1}$	-0.55 (0.19)***
Constant	-0.000098 (0.0223)
Wald chi2(2)	7.93 (Prob > 0.00)

Note: Standard errors are in parentheses; *** significant at 1%.

Source: authors' computations.

Figure 9: Actual and predicted values of change in variance of annual temperature



Source: authors' illustration.

6 Conclusion

Catch per unit effort of most artisanal fish stocks have declined over the past two decades due to overcapitalization of such stocks. The state of the artisanal fishery in Ghana typifies such occurrence. With the increasing poverty trap, coupled with a high unemployment rate within the coastal regions where off-fishing economic activities hardly exist, fishing is a livelihood of last resort. Indeed, the overfishing problem is expected to worsen.

In addition to human activities, it has been found that the coastal climate is getting warmer with potential consequences for capture fisheries. If the warmer climate increases seasonal upwelling and thereby increases primary food production, it will be good for the fishery. On the other hand, if the warmer climate, for example, bleaches corals and rather reduces the food production capability of the aquatic system, the environmental carrying capacity and fish production will decline. In this study, evidence has been found in support of the later case. A dynamic model of the common pool resources management problem in fisheries has been derived and an optimum tax necessary to internalize the congestion externality as well as account for the changing coastal temperature has been proposed. Using data on artisanal fisheries in Ghana, and selected values for price of fish and cost per unit effort, the tax rate is calculated to be within the range of 8 and 21 per cent on cost per unit harvest. Since premix fuel, which is an important input in catch, is subsidized at 18 per cent of ex-refinery price, withdrawing the subsidy could improve the sustainability of fishery. Moreover, the tax must positively correlate with the rising rate of change in temperature as well as the annual variance of the temperature. It is important to note that these results relate to species of low trophic levels and similar research is required for species of higher trophic levels.

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