Global warming and the collapse of the French Guiana shrimp fishery

Bassirou Diop, Nicolas Sanz, Yves Jamont Junior Duplan, Elhadji Mama Guene, Fabian Blanchard, Luc Doyen, Jean-Christophe Pereau

Centre d'Etude et de Recherche en Economie, Gestion, Modélisation et Informatique Appliquée

Document de travail 2015 # 01

Décembre 2015

Global warming and the collapse of the French Guiana shrimp fishery

Diop Bassirou et al.

Global warming and the collapse of the French Guiana shrimp fishery

Diop Bassirou* Nicolas Sanz*
Yves Jamont Junior Duplan* El Hadji Mama Guene*
Fabian Blanchard† Luc Doyen‡ Jean-Christophe Pereau‡

Abstract

This paper studies the biological and economic effects of global warming on the French Guiana shrimp fishery. The sea surface temperature is explicitly introduced into four natural growth functions, among which the Cobb-Douglas function best adjusts the available data. Besides, a Cobb-Douglas harvest function is also estimated, indicating that shrimp production in French Guiana is highly sensitive to the shrimp stock, which implies that global warming may have strong economic implications. We finally consider a centralized resource management of the French Guiana shrimp fishery, that is undertaken in various trend scenarios concerning the sea surface temperature. Under the most plausible scenario, in which the sea surface temperature follows the trend of the last decades, profits and biomass respectively decrease and collapse around the end of the 2020's.

Keywords: Resource management; Climate change; Temperature.
JEL Classification: Q22

---

*Ceregmia, Université des Antilles; Campus de Schoelcher, BP 7209, 97275 Schoelcher Cédex, France. Tel.: +596.(0)596.727.400; Fax: +596.(0)596.727.403; Email addresses: bassirou.diop@etu.univ-ag.fr; nicolas.sanz@univ-guyane.fr; duplanyves@gmail.com; elhadjimama.guene@gmail.com

†Ifremer, Unité Biodiversité Halieutique de Guyane; BP 477, 97331 Cayenne, France. Tel.: +594.(0)594.303.784; Fax: +594.(0)594.308.031; E-mail address: fabian.blanchard@ifremer.fr

‡GREThA, CNRS, Université de Bordeaux; Avenue Léon Duguit, Pessac, France; Tel.: +33.(0)556.842.575; Fax : +33.(0)556.842.966; Email address: luc.doyen@u-bordeaux.fr, jpereau@u-bordeaux.fr

1 Introduction

Shrimp is nowadays the most consumed marine resource in the world. Its growing constitutes a major source of feeding for French Guiana. It represents the third export sector of the latter (25% of the total volume) and remains one of its main industrial sectors. However, the French Guyana shrimp fishery has encountered heavy difficulties in the past two decades. The globalization of the shrimp market, which has led to a decrease of 50% in real prices since 1997, and the long-term increase in fuel prices worldwide, though the 2007 crisis and its consecutive growth slow down has weakened this phenomenon, partly explain the economic problems the fishery has known. Facing this situation, some management rules were progressively adopted or reinforced starting from the creation of the Exclusive Economic Zone in 1977. A total allowable catch (TAC) system was implemented for both the brown and the pink shrimps in 1983 and the management of the fishery is now in compliance with the European legislation. Moreover, some spatial restrictions, forbidding trawling activities in specific coastal zones, were also imposed. The above measures have indeed led to the reduction of fishing effort and harvest levels. The number of active vessels has notably been diminished.

However, despite of the institutional changes mentioned above, the shrimp stock has steadily decreased between 1990 and 2009, mainly due to the fall of the recruitment of the two main species of shrimp targeted. This suggests that other factors, such as exogenous environmental shocks, may have a stronger influence on the French Guiana shrimp fishery than economic factors *per se*. Hannesson *et al.* (2006) provide heavy evidence on fishing industries being very dependent on natural conditions. The French Guiana shrimp fishery might thus probably be affected by the flow of the large amazonian rivers and pure climatic phenomena like “El Niño” or “La Niña”. The sea temperature per see seems also to be the one that mostly affects the quality of offshore waters and thus the productivity of the local marine ecosystem (Sanz *et al.*, 2013). Climate change, and global warming in particular through its effect on the sea temperature, might have therefore the strongest effects on the shrimp stock and harvest levels.

But whereas there is increasing recognition that global warming affects the ecological structure of the marine ecosystem, its impact remains poorly understood (Barange, 2002). Research on its effects on fisheries has been limited and fragmented for a long time (Briones *et al.*, 2006) and its consequences on the economic working of fisheries has been dealt with only over the last few years in the litterature (Garza-Gil *et al.*, 2011). Until now, a majority of existing bioeconomic models still assume that environmental conditions in the ambient marine ecosystem are constant, which is almost

never the case, as underlined by Knowler (2002). Such an assumption has sometimes led to the misspecification of harvest controls, contributing to the diminished state of many exploited living marine resources (Keyl and Wolff, 2008; Stock *et al.*, 2011).

However, since a growing number of studies have identified strong responses of marine resources to climate variability over last years (*e.g.* Lehodey *et al.*, 2006), evidence for responses to anthropogenic climate change is now accumulating (Brander, 2010). The years for which rapid and sustained rises in temperature are expected are now yet to arrive (Levitus *et al.*, 2000), which implies to take this phenomenon systematically into account when building bioeconomic models. A more efficient management of the French Guiana shrimp fishery should thus rely on a global bioeconomic approach, accounting simultaneously for the local economic context and the environmental trends. This might greatly extend the explaining power of the new ecosystem based fisheries management framework.

The aim of this paper is therefore to analyze the potential biological and economic effects that global warming may have on the French Guiana shrimp fishery. In order to do so, we adapt the framework developed by Garza-Gil *et al.* (2011), that preliminary consists in introducing a sea surface temperature variable into different natural growth functions, making it possible to evaluate the impact of global warming on the shrimp stock in a, though superficial, quite direct manner[1]. We further estimate the shrimp harvest function that seems to be highly sensitive to the stock level as French Guiana shrimp is concerned. We then define two scenarios corresponding to two distinct trends followed by the sea surface temperature. The results obtained show how the shrimp stock and the profits it generates might collapse around the end of the 2020's, in the case where the sea surface temperature kept on increasing at the same rate as the one observed over 1990-2009.

The paper is organized as follows. Section 2 describes the French Guiana shrimp fishery and gives the correlation between the sea surface temperature and the observed changes in the fish stock and harvest levels. Section 3 presents the model used to determine the stock, harvest and profit levels that the French Guiana shrimp fishery would reach in the future if it were managed in a centralized manner, depending on two distinct scenarios concerning the trend of the sea surface temperature. Section 4 states the results of the corresponding simulations for the period 2010-2030 in detail, and gives some concluding remarks.

[1]The temperature of waters may be considered as a general proxy of climate change in a first step; the approach used here refers to the Extended Stock Assessment Models (ESAMs; see Stock *et al.,* 2011).

2 The French Guiana shrimp fishery

Two shrimp species are mainly exploited in the French Guiana fishery, the brown and the pink shrimps (resp. *Farfantepenaeus subtilis* and *Farfantepenaeus brasiliensis*). The French Guiana shrimp fishery started in the late 1960's with the US fleet activity. All the vessels are floridean shrimp trawlers, each using two trawls at the same time. Japanese vessels also exploited shrimps, but the whole fleet became progressively French between 1970 and 1990. Over this period, the US-Japanese fleet increased up to 80 trawlers. Since 1992, the whole fleet is only composed with french trawlers targeting shrimps on the continental shell. The stock assessment has been firstly performed each two years by a working group within the institutional and international framework of the Western Central Atlantic Fishery Commission (WECAFC) up to 1999, and has then been undertaken by the Ifremer (French institute of research for the exploitation of the sea) for management advice since the 1980's, allowing for a strong knowledge of the population. The method used for assessment is the well-known "Virtual Population Analysis" (VPA), carried out on a monthly step basis which allows to obtain the recruit abundance as well as the spawning stock biomass and the fishing mortality.

Table A1 (see Appendix) shows series of the shrimp biomass, catches, effort and sea surface temperature for the period 1993-2009 obtained from Ifremer. The biomass has steadily decreased over years though the effort and catch levels have followed quite the same trend. Yet, a total allowable catch (TAC) of 4108 tons for brown and pink shrimps has been adopted, of which 108 tons can be caught by neighbouring countries (Surinam, Trinidad, Barbade). Compared to the historical catch, the TAC level has never been fully achieved. This TAC level has not been changed until 2011, despite the decreasing trends in biomass and landings. In 1991, a license system was introduced for both species. The main objective was initially to limit the number of vessels in order to protect the shrimp resource. Licenses are attributed without any fee. However, the license system did not seem to be in fact an active or efficient resource management tool. Indeed, the year abundance of shrimp is mainly correlated with recruitment but not with effort like *e.g.* the number of vessels or the number of days at sea. The number of licenses was slightly reduced from 69 in 1991 to 63 in 1999, and to 49 in 2010. During this period, the number of active shrimp trawlers was less than the number of licenses (less than half in 2006). The license system could have been a tool to adjust the number of vessels in order to improve economic results, but this objective was not explicitly addressed by the management system. Finally, there exist also some spatial restrictions: in order to limit the impact of trawling on juvenile shrimps and avoid conflicts

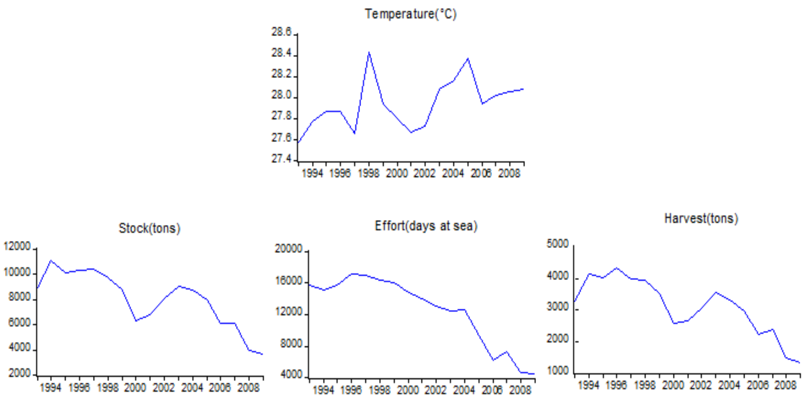

Figure 1: Evolution of Temperature, Stock, Effort and Harvest

with the coastal small-scale fishery, trawling is forbidden in coastal waters less than 30 meters deep. This rule is more restrictive than the spatial limitation applied to trawlers in European waters. All in all, the economic dynamics of the fishery has been characterized by a diminution of the fleet size, to concentrate the fishing activities on a reduced number of profitable vessels (around thirty).

Nevertheless, despite this low effort level, the whole shrimp biomass has strongly decreased between 1993 and 2009 (Lampert, 2011). Table 1 highlights the negative correlation between biomass, effort, catch on the one hand, and the sea surface temperature on the other hand. The French Guiana sea fishing area might be indeed affected by *e.g.* the temperature, which can be considered as a general proxy of global climatic change. The temperature increases between 1970 and 2004 on the Guiana coast. The difference between the average values of these two periods is 0.65°C, with an accentuation of this phenomenon around 1995 (Bernard, 2006) ... Arnason (2006).

Table 1: Correlations between shrimp biomass, catch, sea surface temperature and effort

Variables	Values				
	Biomass	Biomass t+1	Catches	Temperature	Effort
Biomass	1.00				
Biomass t+1	0.83	1.00			
Catches	0.98	0.81	1.00		
Temperature	-0.15	-0.42	-0.13	1.00	
Effort	0.84	0.80	0.87	-0.37	1

3 The model

Before studying the effects of the increase in the sea temperature on the shrimp stock and harvest levels, and on the profit levels they generate, we have to determine which functions illustrate the best the natural growth of the shrimp and its production process. We therefore firstly estimate four natural growth functions that explicitly integrate the sea surface temperature. The logistic function is the most widely used in the economic literature. However, other functions may also be used when the logistic model results in non-significant parameters (Bjorndal, 1988; Clark, 1990; Opsomer and Conrad, 1994; Garza-Gil, 1998; Hannesson, 2006; Nostbakken, 2008):

$$X_{t+1} = aX_t + bX_t^2 + cT_t - H_t \tag{1}$$

$$X_{t+1} = aX_t e^{bX_t + cT_t} - H_t \tag{2}$$

$$X_{t+1} = aX_t^b T_t^c - H_t \tag{3}$$

$$X_{t+1} = aX_t^{b+cT_t} - H_t \tag{4}$$

The above four functional forms are known as the logistic, the Ricker, the Cobb-Douglas, and the Cushing natural growth functions, respectively. The variable X denotes the fish biomass, t, the time (in year), H the harvest, a, b, and c, the parameters that collect biological information, and T, the sea surface temperature. Since the Cobb-Douglas function best adjusts to the series, this is the one that will used to describe the dynamic of the shrimp stock from now on. Usually, the production function used in the economic literature concerning fisheries is also of the Cobb-Douglas form:

$$H_t = \alpha X_t^{\beta_1} E_t^{\beta_2} \tag{5}$$

where α denotes catchability, coefficients β_1 and β_2 represent respectively the elasticities of the catch level, H_t, with respect to the biomass, X_t, and

the effort level, E_t[2]. The effort level corresponds to the total number of days during which the fleet is offshore. It includes the travelling time to the area where the fishing activities take place. If the French Guiana shrimp fishery was managed in a centralized manner, the economic problem of the regulator would consist in choosing total optimal catches that would maximize the current value of the profit flow, $pH_t - wE_t$, generated by the production of shrimp, where p, w, and H_t, represent respectively the unit price of harvest, the cost of effort, and the harvest level at time t, subject to the constraint imposed by the dynamics of the shrimp. The regulator's bio-economic program can thus be written as:

$$\underset{H_t}{Max} \sum_{t=2010}^{2030} \delta^t (pH_t - wE_t) \tag{6}$$

$$\textit{subject to} \quad X_{t+1} - X_t = aX_t^b T_t^c - H_t - X_t$$
$$X_t > 0,\ E_t \geqslant 0,\ X_o \text{ given}$$
$$0 \leq H_t \leq H$$

where δ stands for the discount rate. The solution of the above problem requires the use of optimum control theory (Kamien and Schwartz, 1991). The method gives the optimal value of the shrimp biomass implicitly as follows:

$$\begin{aligned}\beta_1 A X^{-\frac{\beta_1+\beta_2}{\beta_2}} \left(aX^bT^c - X\right)^{\frac{1}{\beta_2}} + \\ \left[p - AX^{-\frac{\beta_1}{\beta_2}} \left(aX^bT^c - X\right)^{\frac{(1-\beta_2)}{\beta_2}}\right] \left(abX^{b-1}T^c - 1\right) \\ - \delta \left[p - AX^{-\frac{\beta_1}{\beta_2}} \left(aX^bT^c - X\right)^{\frac{(1-\beta_2)}{\beta_2}}\right] = 0\end{aligned} \tag{7}$$

As can be seen, the expression of the optimal value of the shrimp biomass depends on the sea surface temperature. The harvest level can be deducted from the biological constraint given by Eq. (3) and the effort level can be obtained from the technological constraint (5). Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The globally averaged combined land and ocean surface temperature show a warming of 0.85 [0.65 to 1.06] °C over the period 1880 to 2012 (IPCC, 2014: Climate Change 2014). We are now in a position to analyze the effects of the rise in the sea surface temperature on the stock, the harvest and the profits of the French Guiana shrimp fishery. Two

[2] $\beta_1 \neq \beta_2 \neq 1$.

environmental scenarios are considered over a time horizon that extends to 2030. The first scenario corresponds to a sea surface temperature rise at the same rate as over the period 1993-2009, *i.e.* about 0.025 °C per year. It corresponds to a statu-quo scenario. In a second scenario, we assume that the sea surface temperature will increase 10% more than the trend observed over the considered period.

4 Results

We first estimate the four natural growth functions using the data shown in Table A1 (see Appendix). Results are presented in Table 2 for the Cobb-Douglas form, for which parameters are significant, and in Table A2 for the other functions that did not fit the data.

Table 2: Estimates of the Cobb-Douglas natural growth function

	$X_{t+1}+h_t= aX_t^bT_t^c$
a	
$\ln(a)$	27.03 (0.023)
b	1.01 (0.000)
c	-8.07 (0.022)
R^2	0.89
R^2 adjusted	0.88
JB	2.69
Q-Stat	6.38
LM (ARCH)	1.26
AIC	-1.50

Notes: p-values in parentheses; all coefficients are statistically significant at the 5% level.

JB is the Jarque-Bera statistic of the normality test; Q-Stat is the Ljung-Box statistic used in the correlation test;

LM (Lagrange multiplier) is the one used in the heteroscedasticity test; AIC (Akaike) is the statistic used in the prediction error model.

Table 3 presents the estimates concerning the French Guiana shrimp production function. The major statement is that the elasticity of harvest with respect to the stock is very near from one (0.91), making production mainly sensitive to the stock relative to fishing effort.

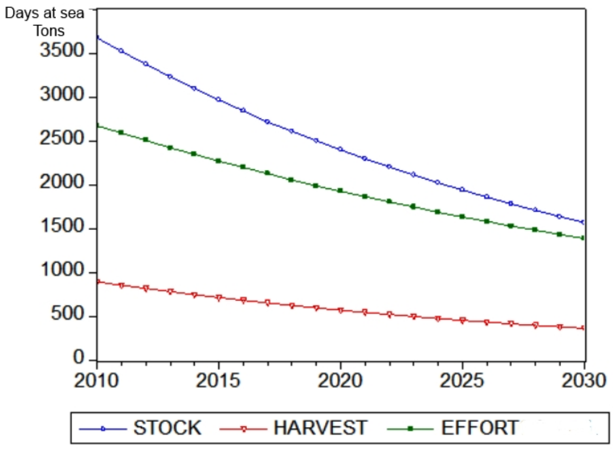

Figure 2: Evolution of stock, effort and harvest

Table 3: Estimates of the shrimp harvest function

$H_t=\alpha X_t^{\beta_1} E_t^{\beta_2}=0.27X_t^{0.91}E_t^{0.11}$
$\ln H_t=\ln\alpha + \beta_1 \ln(X_t) + \beta_2 \ln(E_t)$
$\ln H_t$=-1.2(0.000)+0.92$\ln(X_t)$(0.000)+0.11$\ln(E_t)$(0.001)
R^2 = 0.99
R^2 adjusted = 0.98
F-Stat = 719
DW = 1.63
JB = 0.09

Notes: p-values in parentheses; all coefficients are statistically significant at the 5% level.

F-Stat and DW are respectively the Fisher and the Durbin-Watson statistics;

JB is the Jarque-Bera statistic of the normality test.

In the Cobb-Douglas case retained, the successfull CUSUM test (Brown *et al.*, 1975), which is based on the cumulative sum of the recursive residuals and has been illustrated in Figure 3 of the Appendix, ensures the stability of the equation parameters over the period 1993-2009, allowing for robust forecasts over the period 2010-2030. The forecasts concerning the shrimp stock, fishing effort and harvest are presented in Figure 2.

We can now use the estimates of the natural growth and production functions to undertake the simulations that will give the trends for the stock, harvest, and profit levels until 2030. The observed fall in harvest may be

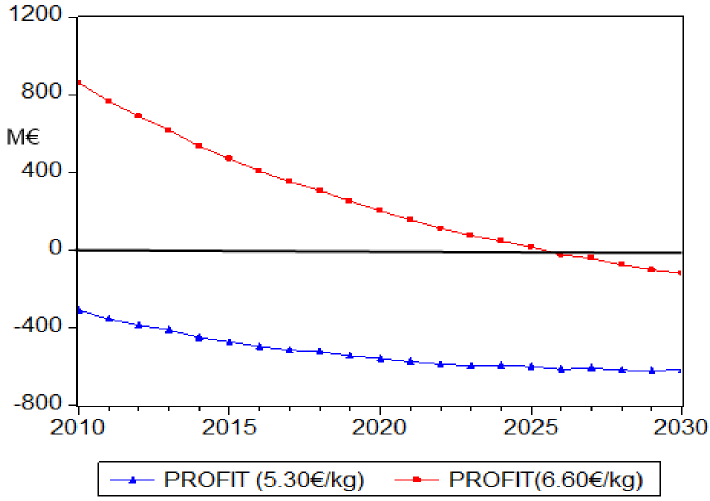

Figure 3: Evolution of Profits (no subsidy/State subsidy of 1,30€/kg)

due to either a decrease in the stock or in the effort level, or both of them. However, Table 2 indicates that in the studied fishery, the stock-elasticity of harvest is 0.91, whereas the effort-elasticity of harvest is 0.11. Hence, harvest is mostly sensitive to the stock. This suggests that the rise in the sea surface temperature, through its direct effect on the stock (see Table 2), plays the main role in the fall of harvest.

As far as corresponding profits are concerned, the unit price of landings, p, has been chosen equal to 5.30€/kg, and the cost per unit of effort, w, is 1900€/day, which corresponds to the mean cost per day at sea. A second base of 6.30€/kg, that includes a 1.30€/kg State subsidy that has been distributed to fishing firms since 19??, was also used. Forcasts about profits are illustrated in Figure 4, which clearly indicates that non-subsidized firms would make negative profits over the whole predictive period. The situation is slightly different if the sector is subsidized, as this is the case in reality. In this case, profits remain positive for almost the entire considered period, but decrease steadily until 2030, while becoming slightly negative from 2026, due to the collapse of the stock (see Figure 3).

Our results indicate first that a Cobb-Douglas function, whose arguments are the stock and the sea surface temperature, constitutes the most appropriate model to illustrate the French Guiana shrimp natural growth. Secondly, they suggest that global warming has a substantial impact on the shrimp stock and harvest levels. According to our most credible scenario, climate change may induce the collapse of the stock, harvest and profits around the

end of the 2020's. This phonomenon can be mainly explained by the fact that as far as the French Guiana shrimp is concerned, harvest is mainly sensitive to the trend of the stock *per se*. Consequently, environmental factors such as the sea temperature seem to play a major role, through their effects on the stock, on the trend of the production levels, and thus, on the overall profitability of the fishery. Besides, the fact that the stock elasticity of harvest is near from one implies that global warming influences uppermost the harvest of the species, such as shrimp, for which the level of the stock is crucial. The negative effect of the rise in the sea surface temperature on the stock is largely stronger than the positive effect of the fall in effort and harvest. This reflects the prevalence of pure environmental phenomena over the economic factors *per se*. To save the French Guiana shrimp fishery, it is crucial to try to limit the sources of climate change instead of trying to deeply modify economic practices of the sector, which may lead to misunderstandings and conflicts.

The results obtained in this paper answer partly to the limits underlined by Stock *et al.* (2011). For living marine resources management strategies to be effective in a changing climate, they must more directly consider how climate is impacting resource dynamics. Reliably predicting the impacts of future climate on living marine resources requires a good understanding of the mechanisms through which climate acts.

Appendix

Table A1: The French Guiana shrimp fishery

Year	Biomass (tons)	Total catches (tons)	Effort (days of fishing)	Sea surface temperature ($^{\circ}C$)
1993	8929	3275	15,682	27.57
1994	11126	4156	15,154	27.77
1995	10120	4010	15,723	27.87
1996	10303	4323	17,116	27.86
1997	10409	3984	16,992	27.66
1998	9739	3940	16,320	28.43
1999	8765	3495	16,013	27.94
2000	6302	2572	14,764	27.80
2001	6809	2651	14,026	27.67
2002	8120	3043	13,058	27.72
2003	9110	3557	12,504	28.08
2004	8778	3325	12,550	28.16
2005	8026	2943	9,266	28.37
2006	6173	2222	6,141	27.94
2007	6096	2369	7,278	28.02
2008	4000	1496	4,667	28.05
2009	3705	1323	4,489	28.09

Table A2: Estimates of the Cushing, logistic, and Ricker natural growth functions

	$X_{t+1}+h_t = aX_t^{b+cT_t}$	$X_{t+1}+h_t= aX_t+bX_t^2+cT_t$	$X_{t+1}+h_t= aX_te^{bX_t+cT_t}$
a		2.10 (0.055)	1.19 (0.105)
$\ln(a)$	0.13 (0.884)		6.80 (0.295)
b	1.89 (0.000)	-4.17E-05 (0.478)	-2.15E-05 (0.794)
c	-0.03 (0.024)	-104.48 (0.414)	-0.28 (0.027)
R^2	0.89	0.82	0.89
$R^2{}_{\text{adjusted}}$	0.87	0.80	0.87

Notes: p-values between brackets

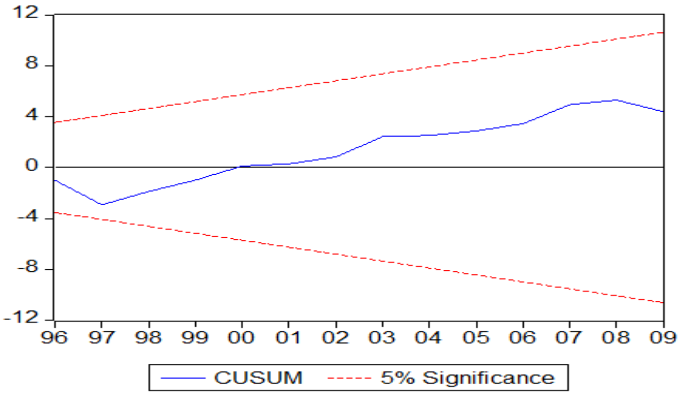

Figure 4: Cumulative Sum of the recursive residuals (CUSUM)

Table A3: Results from the two scenarios about the sea surface temperature (2010-2030)

				Increase of 0.025 °C/year				Increase of +10%
Year	Biomass (tons)	Catch (tons)	Effort (days)	Temperature (°C)	Biomass	Catch	Effort (days)	Temperature (°C)
2010	3677.848	901.460	2675	28.09	3677.848	901.460	2675	28.09
2011	3523.882	863.416	2594	28,115	3636,200	861.929	2532	28,118
2012	3376.499	827.010	2509	28,140	3468,853	824.166	2425	28,145
2013	3235.411	792.169	2425	28,165	3309,373	788.090	2308	28,173
2014	3100.346	758.825	2351	28,190	3157,382	753.624	2181	28,200
2015	2971.039	726.913	2273	28,215	3012,522	720.696	2070	28,228
2016	2847.240	696.369	2202	28,240	2874,451	689.2361	1982	28,255
2017	2728.710	667.135	2131	28,265	2742,844	659.176	1946	28,283
2018	2615.221	639.152	2057	28,290	2617,392	630.453	1787	28,310
2019	2506.552	612.366	1992	28,315	2497,802	603.006	1713	28,338
2020	2402.495	586.725	1928	28,340	2383,794	576.778	1611	28,365
2021	2302.851	562.180	1870	28,365	2275,102	551.714	1535	28,393
2022	2207.428	538.681	1809	28,390	2171,473	527.761	1457	28,420
2023	2116.044	516.185	1752	28,415	2072,667	504.868	1381	28,448
2024	2028.524	494.646	1691	28,440	1978,453	482.988	1313	28,475
2025	1944.701	474.025	1637	28,465	1888,615	462.075	1271	28,503
2026	1864.416	454.280	1589	28,490	1802,944	442.085	1208	28,530
2027	1787.517	435.374	1533	28,515	1721,244	422.978	1129	28,558
2028	1713.857	417.270	1488	28,540	1643,326	404.713	1081	28,585
2029	1643.298	399.934	1439	28,565	1569,013	387.252	1037	28,613
2030	1575.706	383.333	1392	28,590	1498,132	370.560	981	28,640

Table A4: Profits generated by the French Guiana shrimp fishery (K€)

Year	Profit (5.30 €/kg)	Profit (6.60 €/kg)
2010	-308,710	862.589
2011	-354,717	767,183
2012	-385,137	689,962
2013	-410,493	619,106
2014	-449,784	535,615
2015	-472,069	471,730
2016	-496,886	407,913
2017	-515,003	352,096
2018	-523,370	307,329
2019	-542,580	253,019
2020	-558,225	203,574
2021	-574,413	156,186
2022	-587,164	112,253
2023	-595,482	75,317
2024	-595,247	46,952
2025	-598,338	17,861
2026	-613,443	-23,243
2027	-607,678	-42,178
2028	-617,333	-75,233
2029	-620,014	-101,314
2030	-616,099	-118,199

References

Arnason, R. (2006), "Global warming, small pelagic fisheries and risk". In *Climate Change and the Economics of the World's Fisheries* (eds R. Hannesson, M. Barange and S.F. Herrick Jr), Edward Elgar Publishing, Camberley, UK, 1-32.

Barange, M. (2002), "Influence of climate variability and change on the structure, dynamics and exploitation of marine ecosystems", *Issues in Environmental Science and Technology* 17, 57–82.

Bernard, C. (2006), "Changement climatique, conséquences potentielles pour la biodiversité chtyologique et pour la pêche côtière en Guyane française entre 1970 et 2005", Mémoire de master 2, Geni, A. L., Université La Rochelle, IFREMER

Brown, R. L., J. Durbin, and J. M. Evans (1975), "Techniques for Testing the Constancy of Regression Relationships Over Time", *Journal of the Royal Statistical Society*, Series B, 37, 149-192.

Bjorndal, Trond. (1988), "The Optimal Management of North Sea Herring", *Journal of Environmental Economics and Management* 15, 9-29.

Briones, R., Garces, L. and Ahmed, M. (2005) "Climate change and small pelagic fisheries in developing Asia: the economic impact on fish producers and consumers". In: *Climate Change and the Economics of the World's Fisheries* (eds R. Hannesson, M. Barange and S.F. Herrick Jr), Edward Elgar Publishing, Camberley, UK, 215-235.

Clark, C. (1990), *Mathematical Bioeconomics. The Optimal Management of Renewable Resources*, 2nd edition, Wiley Interscience Publication, New York.

Dunlap, R. E. (1991), "Trends in public opinion toward environmental issues: 1965 à 1990", *Society & Natural Resources* 4(3), 285-312.

FAO (2012), *State of World Fisheries and Aquaculture*, State of World Fisheries and Aquaculture (FAO), Rome.

Garza-Gil, M. D., Torralba-Cano, J., Varela-Lafuente, M. M. (2011), "Evaluating the economic effects of climate change on the European sardine fishery", *Regional Environmental Change* 11, 87-95.

Hannesson, R., Barange, M., Herrick, S. J. (2006), *Climate Change and the Economics of the World's Fisheries*, Edward Elgar Publishing Limited, Cheltenham, UK.

IPCC (2014), *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kamien, M., Schwartz, N. (1991), *Dynamic Optimization. The Calculus of Variation and Optimmal Control in Economics and Management*, North Holland, New York.

Knowler, Duncan. (2002), "A Review of Selected Bioeconomic Models with Environmental Influences in Fisheries", *Journal of Bioeconomics* 4, 163-181.

Lampert, L. (2011), *Etude de la crise de la pêche de la crevette en Guyane. Volume 1 : Effets de la pêcherie-hypothèses des causes*, Rapport RST Ifremer/Biodivhal 2011-5, Cayenne.

Levitus S, Antonov JI, Boyer TP, Stephens C. (2000), "Warming of the world ocean", *Science* 287, 2225-2229.

Nostbakken, L. (2008), "Stochasic Modelling of the North Sea Herring Fishery under Alternative Management Regimes", *Marine Resource Economics* 23, 65-86.

Sanz N., Diop B., Blanchard F., Lampert L. (2013), "On the influence of environmental factors on harvest : the French Guiana shrimp fishery paradox", *Ceregmia-Université des Antilles Working Paper* 2013-04.

Stock, Charles A., Alexander, Michael A., Bond, Nicholas A., Brander, Keith M., Cheung William W.L., Curchitser, Enrique N., Delworth, Thomas L., Dunne, John P., Griffies, Stephen M., Haltuch, Melissa A., Hare, Jonathan A., Hollowed, Anne B., Lehodey, Patrick., Levin, Simon A., Link, Jason S., Rose, Kenneth A., Rykaczewski, Ryan R., Sarmiento, Jorge L., Stouffer, Ronald J., Schwing, Franklin B., Vecchi, Gabriel A., Werner, Francisco E. (2011), "On the use of IPCC-Class Models to Assess the Impact of Climate on Living Marine Resources", *Progress in Oceanography* 88(1-4), 1-27.