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# A MODEL TO PREDICT CLIMATE CHANGE IMPACT ON FISH CATCH IN THE INDIAN OCEAN

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**ABSTRACT--**Temperature plays a very important role for fish production in the lake, pond, river, ocean and other water-bodies where the fish lives. The assessment of the impact of the water temperature changes on fish catches in world fishery is essential for sustainable management of the world fishery resources. A new method for forecasting of fish catch of the major fishing areas in the World Oceans under the global climate change (temperature) has been developed. This method predicts the tendency (increase or decrease) for fish catch with quantitative predictor's power if the temperature is known. This method has been applied to the Indian Ocean to assess the climate change impact on fish catch. Based on the temperatures predicted using CLIMate-BiospheRE model for the years 2000–2100, a decrease of fish catch in the Indian Ocean with the confidence of the predictor's power (≥ 90%) have been predicted.

**Keywords:** Climate change impact; Surface water temperature; Fish catch; Statistical forecasting.

## INTRODUCTION

Populations of fish and other aquatic organisms are greatly influenced by several factors such as physical, chemical, biological and meteorological factors. Since they are poikilothermous, one of the leading factors is the temperature of the surface layers of the ocean. There is a very close correlation between the catches of such species as salmons, Japanese sardinops, Chilean sardinops, Californian pilchard, and variations of annual air temperature in the North Pacific Ocean (Moiseev, 1989).

Fish reproduction and other biological activities are mainly controlled by the temperature of the water. Food consumption of fish is a function of fish species, fish mass, water temperature, ammonia nitrogen concentration and dissolved oxygen concentration (Winberg, 1960; Jorgensen, 1976; Piper et al., 1982 and Haight, 1983). The requirement of fish for dissolved oxygen varies with temperature, physiological state, age, time of the day, season, food consumption etc (Elmon and Hayes, 1960; APHA, AWWA & WPCF, 1981).

Conrad (1986) and Clark (1987) described a basic/general bioeconomic production model and Allen (1987) developed a single species dynamic non-spatial fishing model and a multi-species spatial dynamic fishing model. None of these models consider the environmental variable – the effects of temperature on fish populations.

Criddle et al. (1998) developed bioeconomic model for the eastern Bering Sea walleye pollock fishery which suggests that oceanographic conditions associated with lagged temperature anomalies exert a significant influence on fish catch and have a persistent effect on total biomass.

Temperature is one of the single most important environmental variables affecting all aquatic organisms. In accordance with the arguments above, it is evident that there is a sufficiently strong correlation between the dynamics of temperature fields and the fish catch in the World Oceans. Such a correlation can be used for the construction of some statistical criterion which would allow us to separate "good" and "bad" fishing years defined by variations of the temperature field to be used. In turn, this criterion would be used as some kind of statistical predictor which can predict a fishing situation under global climate change.

## A MODEL OF CLIMATE CHANGE INPACT ON FISH CATCH

Several studies reported that catches of fish in the oceans are affected by surface water temperature. A knowledge of the impact of the temperature on fish catches in world fishery is essential for sustainable management of the world fishery resources. To develop a new method for climate impact on world fishery

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resources the data on historical behaviour of surface water temperature and fish catches are to be analyzed to search for the dynamics of temperature and fish catches based on the previous records. On based on the previous records. On the basis of the information contained in the processed data a new method for forecasting of climate change impact on world fisheries is developed.

## DATA PROCESSING

Two categories of data were analyzed and processed to assess the dynamics of spatial temperature distribution and fish catches for the oceans of the fishery resources. These are annual average surface water temperature and annual catches obtained from Potsdam Institute for Climate Impact Research (PIK) and FAO Yearbook of Fishery Statistics: Catches and Landings (1964-1995) respectively.

The familiar average of a set of temperature, $T(x,y,t)$, denoted by $M_1(t)$, is given by the formula

$$M_1(t) = \frac{1}{S}\iint_{\Omega} T(x,y;t)dxdy \qquad (1)$$

where, $T(x,y,t)$ *is* the annual sea surface temperature
t is a number of year (t = 1, 2, 3,..., n)
n is the number of years
$x$, $y$ are the geographical co-ordinates

Where the integral $\iint_{\Omega} T(x,y,t)dt$ is calculated numerically on COADS 2°×2° grid, and $S$ is the area of the domain Ω; $M_1(t)$ is called the first moment or arithmetic mean or mean. Fig.1 shows dynamics of the mean annual temperature for the Indian Ocean. Now, it can be shown that the numerical value of the first moment or the mean, represents the point on the *xy*-axes.

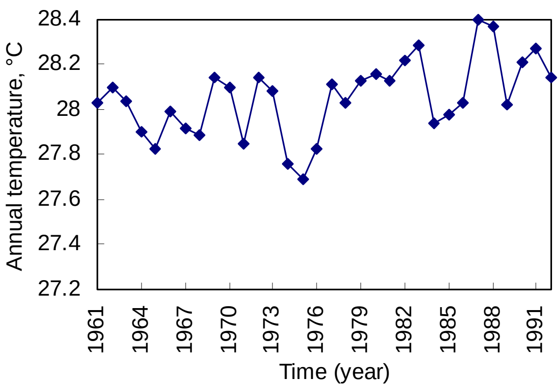


**Fig.1 Dynamics of the mean annual temperature for the Indian Ocean.**

The second, third and fourth moments of a set of temperatures $T(x,y,t)$-distribution is described by the following formula

$$M_k(t) = \frac{1}{S}\iint_{\Omega} (T(x,y;t) - M_1(t))^k dxdy \qquad (2)$$

Thus, it differs from the first moments $M_1(t)$ given by the Equation (1), in that it uses the power k (k=2,3,4) of the variable rather than the variable itself. Since the first moment gives the desired location information, the information to be obtained from the second, third and fourth moments should be additional information. Really four moments are rather sufficient for describing the characteristics of any relatively smooth distribution.

Since it is more appropriate to use normalized values of moments, the following equation is introduced to normalize the values of the moments:

$$m_k(t) = \frac{M_k(t) - M_k^*}{\sigma_k}, \quad k = 1,2,3,4 \qquad (3)$$

where

$$M_k^* = \frac{1}{n}\sum_{t=1}^{n} M_k(t), \ \sigma_k^2 = \frac{1}{n-1}\sum_{t=1}^{n}(M_k(t) - M_k^*)^2$$

The standard presentation of fisheries statistics (FAO, Yearbook of Fishery Statistics, 1964-1995) at the Indian Oceans shows the statistics of fish catch separately for each different species (or group of species) from the years 1970-1989. According to the species the fish catches data before 1970 are not available either in FAO Yearbook of Fishery Statistics or other Yearbook of International Statistics.

Let $N_i(t)$ be the biomass of $i$-th species at year $t$. Then the species diversity (a criterion which is close to information entropy) will be:

$$H(t) = -\sum_{i=1}^{n} p_i \ln p_i \qquad (4)$$

where $p_i = N_i(t)/N$ is the frequency of the i-th species
$N = \sum_{i=1}^{J} N_i(t)$ is the total biomass of the i-th species
J is the number of species

Let us consider the dynamics of the value, $H(t)$, with respect to time. If the value considered as a function of time is changed significantly, it means that the dynamics of the distribution of frequencies $p_i$ is very important for the description of the system dynamics as a whole. On the contrary, if $H(t)$ is not changed or if its change is sufficiently smooth, it means that the change of $\vec{p}$-distribution is not an important characteristics of the system dynamics. From Fig.2 it can be concluded that if the value of diversity is not significantly changed with time t, then such a value as the total fish catch, $N$, can be used as the main dynamic variable, practically without loss of information about the dynamic properties of the system.

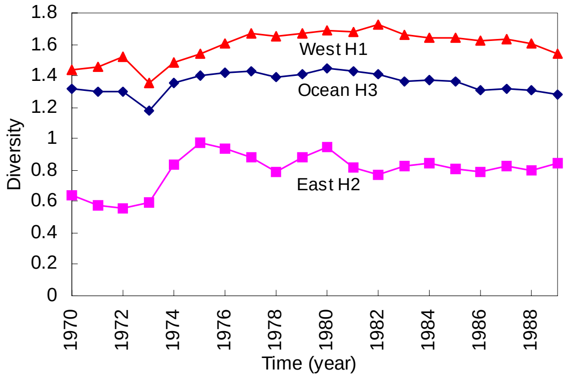


**Fig.2 Dynamics of diversity for the Eastern and Western parts and for the whole Indian Ocean.**

The dynamics of the total fish catch in Indian Ocean is shown in Fig.3. The dynamics is very close to an exponential growth. It is assumed that the dynamics consists of two components: the first one is pure exponential growth defined by economic factors only, and the second one is oscillations around this exponential curve defined only by the variation of the climate factors (temperature). Therefore, if $N(t),\ t = 1,2,\ldots$ is the total fish catch and the data on total catch are fitted to the equation

$$\hat{N}(t) = a\exp(bt), \quad t = 1,2,\ldots \quad (5)$$

where a and b are constant

$\hat{N}(t)$ is the predicted total fish catch.

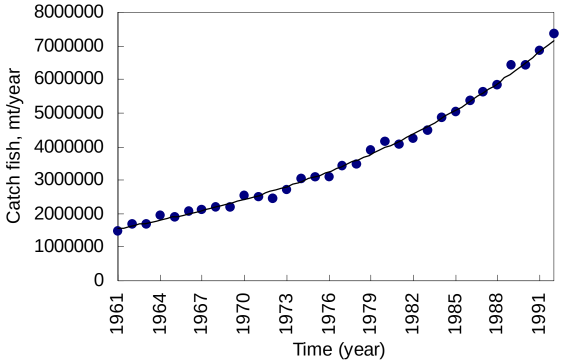


**Fig.3 Dynamics of the total fish catch for the whole Indian Ocean. ••• Observed and ___ Predicted.**

The following regression line was developed to describe the exponential growth.

$$\hat{N}(t) = 1499400\exp(0.048\,t) \qquad (6)$$

Fig.3 shows the observed data of total fish catch and the regression line.

Again, the relative deviation is computed from the relation

$$w(t) = \{N(t) - \hat{N}(t)\} / \hat{N}(t), \quad t = 1,2,\ldots \quad (7)$$

and it can be considered as some relative value of influence for temperature.

## CONSTRUCTION OF THE PREDICTOR

The predictor is a rule, in accordance to which the dynamics of fish catch $w(t)$ for next time, i.e. for new values of $m_1,..,m_4$ (moments of a future temperature distribution) can be predicted. Let us assume that the values of $w(t)$ (both for previous years and for next time) can be presented in the form

$$w(t) = \sum_{k=1}^{4} \alpha_k m_k(t), \ \ t = 1,\ldots,n \qquad (8)$$

Really $n$=32>>4, and this system can be considered as an over-determined linear algebraic system in respect to $\alpha_k$ which can be solved by the Gauss method (the method of least squares, Hoel, 1966).

Let us assume that the solution of Equation (8) is: $\left\{\alpha_k^*; k = 1,2,3.4\right\}$. It is obvious that

$$u(t) = \sum_{k=1}^{4} \alpha_k^* m_k(t) \neq w(t), \ \ t = 1,\ldots,n \quad (9)$$

Fig.4 shows the values $w(t)$ and $u(t)$ and it can be noted that they differ from each other.

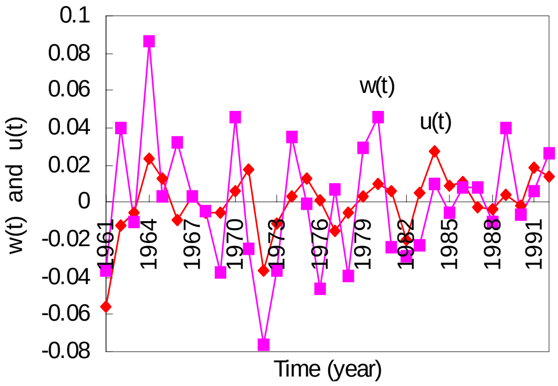


**Fig.4 Values of $w(t)$ and $u(t)$.**

It is obvious that either $w(t)$ or $u(t)$ are random values, but that their sequential means can be connected by temporal correlation. The self-correlated functions of w(t) and u(t) are calculated by the following formulas (Svirezhev, 1996).

$$SC_w(\tau) = \frac{1}{(n-\tau-1)s_w^2}\sum_{t=1}^{n-\tau}\left[w(t)-\hat{w}\right]\cdot\left[w(t+\tau)-\hat{w}\right] \quad (10)$$

where

$$\hat{w} = \frac{1}{n}\sum_{t=1}^{n} w(t), \quad s_w^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left[w(t)-\hat{w}\right]^2$$

and

$$SC_u(\tau) = \frac{1}{(n-\tau-1)s_u^2}\sum_{t=1}^{n-\tau}[u(t)-\hat{u}]\cdot[u(t+\tau)-\hat{u}] \quad (11)$$

where

$$\hat{u} = \frac{1}{n}\sum_{t=1}^{n} u(t), \quad s_u^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left[u(t)-\hat{u}\right]^2$$

The self correlated functions of w(t) and u(t) for total fish catch are shown in Fig.5 and it can be noted that the correlation is sufficiently weak. The maximum correlation of the self correlated function of u(t) are found at $\tau$=3, 5 and 11. In the next one or two years the correlation becomes very small. This is especially true for values of $u(t)$. This indicates that $u(t)$ can be considered as a $\delta$-*correlated* stochastic process, and the sequence $u(t)$ is the set of *statistically independent* values for study of which the methods of variational statistics may be used.

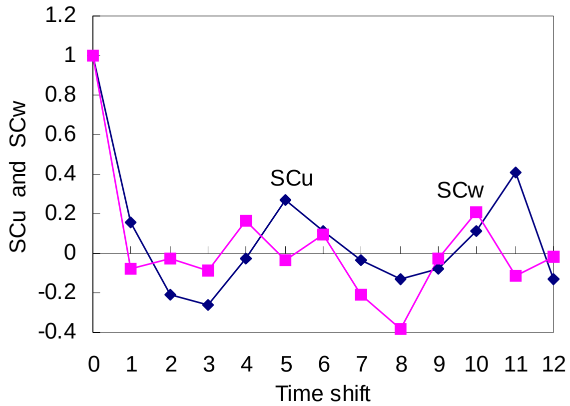


**Fig.5 Self-correlated functions $SC_w(\tau)$ and $SC_u(\tau)$. Time $\tau$ is a shift between two temporal points**

The histogram for $u(t)$-values is shown in Fig.6 and this hints that there are two different unimodal distributions. This gives a chance of creating a statistical decision using the statistics of $u(t)$-values.

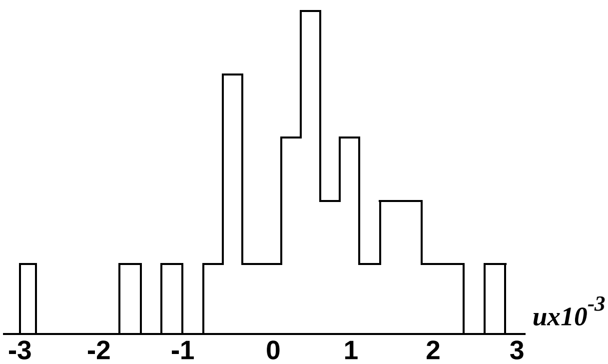


**Fig.6 Histogram for $u(t)$-values.**

All these arguments allow us to formulate the following decision rule (predictor):

**1.** Let there be a forecast of temperature distribution for a given region and for some $j$-th ($j>n$) year: $T(x,y,t_j)$, $x,y \in \Omega$ (observed or, for instance, predicted by General Climate Model). Using Equations (1) - (3) for calculation of moments $m_k(t_j)$ of the distribution the following values are computed (Svirejhev, 1996):

$$m_k(t_j) = x_k^j / \sigma_k^j \quad (12)$$

where $x_k^j = \frac{n}{n+1}\left[x_k^n + \left[M_1(t_j) - M_1(t_n)\right]\right]$

$$\sigma_k^j = \sqrt{\frac{n-1}{n}(\sigma_k^n)^2 + \frac{n+1}{n^2}(x_k^j)^2}$$

$$x_k^n = m_k(t_n)\times\sigma_k^n = M_k(t) - M_k^*$$

**2.** Then the value of u($t_j$) is calculated as

$$u(t_j) = \sum_{k=1}^{4}\alpha_k^* m_k(t_j) \quad (13)$$

where $\alpha_k^*$, $k = 1,2,3,4$ is the solution of Equation (8) for previous observed $n$ years. Hence predictor rule is that

- **if $u(t_j) > 0$ then the fish catch would be higher than predicted by the curve of the mean economic growth (climate change has a positive influence);**

- **if $u(t_j) < 0$ then the fish catch would be lower than predicted by the curve of the mean economic growth (climate change has a negative influence).**

Therefore, using the predictor $u(t_j)$ a deviation of fish catch from the exponential curve of economic growth can be forecasted.

## ESTIMATION OF THE PREDICTOR'S POWER

When the values $u(t)$ for $t$=1,...,$n$ are calculated using the known coefficients $\alpha_k^*$ and it can be noted that these values differ from observed values $w(t)$. Let us distribute the values $u(t)$ into two sets $L^-$ and $L^+$ in accordance with the following rules:

$$u^-(t) = u(t) \in L^- \quad \text{if} \quad w(t) < 0 \quad \text{and}$$
$$u^+(t) = u(t) \in L^+ \quad \text{if} \quad w(t) > 0 \quad (14)$$

Here it is assumed (this is a very important assumption) *that the values* $u^-$ and $u^+$ *belong to two* different normal distributions $N^-$ and $N^+$ with different means $v^- < 0$ and $v^+ > 0$. Then all the elements of $L^-$ must belong to $N^-$ and all the elements of $L^+$ must belong to $N^+$. It is an advantage of this assumption that both the Central Limit Theorem (really $n >> 1$) and the statistical independence of *u*-values are indicated. Then the **t**-criterion based on **t**-statistics may be used to estimate the power of the predictor (Lehmann, 1959).

Applying these to two sets of **t**-statistics two values of **t**-criterion are obtained:

$$\mathbf{t}^- = \frac{\sqrt{n^-}}{s^-}\left|\hat{u}^-\right| \qquad (15)$$

where $n^-$ is the number of elements in the set $L^-$,

$$\hat{u}^- = \frac{1}{n^-}\sum_{t\in L^-} u^-(t),\; s^- = \left\{\frac{1}{n^-}\sum_{t\in L^-}(u^-(t)-\hat{u}^-)^2\right\}^{1/2}$$

and

$$\mathbf{t}^+ = \frac{\sqrt{n^+}}{s^+}\left|\hat{u}^+\right| \qquad (16)$$

where $n^+$ is the number of elements in the set $L^+$,

$$\hat{u}+ = \frac{1}{n^+}\sum_{t\in L^+} u^+(t),\; s^+ = \left\{\frac{1}{n^+}\sum_{t\in L^+}(u^+(t)-\hat{u}^+)^2\right\}^{1/2}$$

The following two statistical hypotheses must be tested: $u(t_j) \in N^-$ and $u(t_j) \in N^+$. Using the one-sided **t**-criterion the following condition is obtained: if $u(t_j) < 0$ then $u(t_j) \in N^-$ with probability $\boldsymbol{P}^-$, and if $u(t_j) > 0$ then $u(t_j) \in N^+$ with probability $\boldsymbol{P}^+$.

These probabilities are defined in the following way:

Let $\mathbf{t}^-$ be the value calculated by Equation (15). Using the table of the Student **t**-distribution the value which is equal to $\mathbf{t}^-$ for $n^-$ degrees of freedom can be found. Then the corresponding probability α ( $\Pr\left\{|\mathrm{t}| > \left|\mathrm{t}(n^-)\right|_{1-\alpha}\right\}$) is found. At last, $\boldsymbol{P}^-$ = 1-α/2 is also found. The probability $\boldsymbol{P}^+$ is defined analogously.

The values $\boldsymbol{P}^-$ and $\boldsymbol{P}^+$ can be used as some measures of the predictor's power. And finally the decision rule with predictor's power is that

- **if $u(t_j) > 0$ then the fish catch would be higher than predicted by the curve of the mean economic growth (climate change has a positive influence); this statement is true with probability $\boldsymbol{P}^+$.**
- **if $u(t_j) < 0$ then the fish catch would be lower than predicted by the curve of the mean economic growth (climate change has a negative influence); this statement is true with probability $\boldsymbol{P}^-$**

## APPLICATION OF THE MODEL TO THE INDIAN OCEAN

Petoukhov et al (1998) developed a model CLIMBER-2 (CLIMate-BiospheRE model) for prediction of the performance for present climate conditions. The future temperature differences of every 10-year interval are taken from the "CLIMBER-2 simulated sea surface temperature anomalies 2000-2100" for the Indian Ocean and these differences also increase for every interval. From these data, the future average temperature and also the dynamics of $u(t)$-values of this region are calculated and these are shown in Fig.7 and Fig.8 respectively.

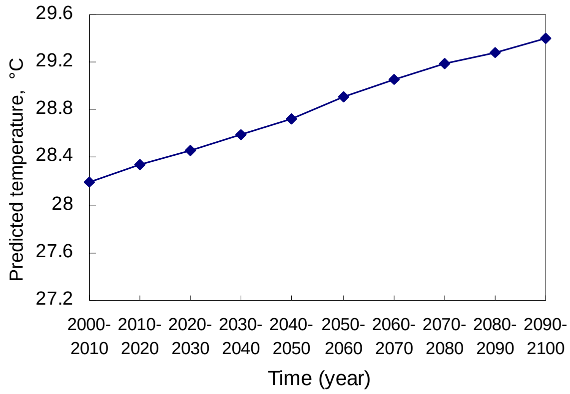


**Fig.7 Predicted temperature for the Indian Ocean**.

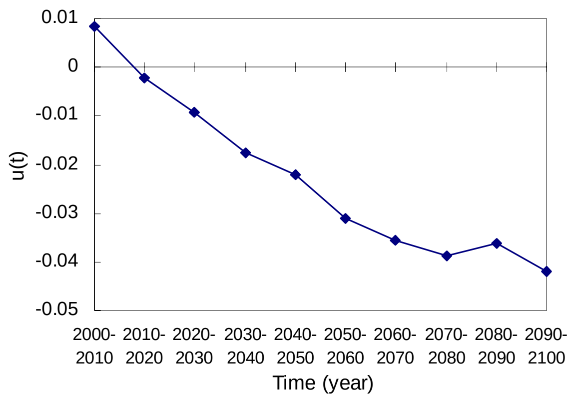


**Fig.8 Predicted $u(t)$-values for the Indian Ocean.**

The $u(t)$-values for the Indian Ocean decrease from positive to negative values (Fig.8). This means that the global climate change will negatively influence fish catch in the next century (years 2000 to 2100).

Validation of a model is a process by which confidence in the model is to be developed for some particular purpose. In this statistical forecasting model the predictor power is the probability with which the prediction is made and in this case the statement is true with a probability of $P^{-} = 90\%$.

## CONCLUSIONS

A new method of "multi-moment statistical analysis and forecasting" has been developed for prediction of climate change impacts on fishery and the salient features of the method are:

(1) a statistical relation between the sea surface temperature and fish catch has been successfully developed.
(2) a predictor which allows to predict the tendency (increase or decrease) of fish catch if the temperature is known has been successfully constructed.
(3) the predictor's power has also been quantitatively estimated.
(4) based on the temperatures using CLIMBER-2 model for the years 2000–2100, a decrease of fish catch in the Indian Ocean, with the confidence of the predictor's power (≥ 90%) is predicted.
(5) the fish catch in the Indian Ocean will be decreased. This can be explained in a way that the sea surface temperature will be increased every year and it will be higher than the optimum temperature for fish growth.
(6) This research will also generate sufficient scientific information for researchers, fishermen, consumers and fish processors, nationally and internationally.

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