A SYSTEM OF INDICATORS TO UNDERSTAND THE SOCIOECONOMIC AND ECOLOGICAL INTERACTIONS AND MANAGE THE FISHERIES SUSTAINABILITY

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ABSTRACT

In most of the coastal countries, the fisheries enable to satisfy multiple socio-economic needs such as food safety, public receipts, employment and so on. It is especially true in many coastal developing countries where fisheries constitute a considerable source of food and incomes. However, the strong pressure on the fisheries resources becomes a great threat for the fisheries sustainability. This context of overexploitation is also marked by a great diversity of stakeholders intervening in the fisheries governance. Thus, a better comprehension of the socio-economic and ecological interactions and the stakes of the fisheries governance is essential to elaborate management policies more adapted to a transition towards sustainability. Based on the case of the Senegalese fisheries, this paper is centered on the selection process of some socioeconomic and ecological indicators whose thorough analysis allows us to propose a strategy of adaptive management of the fisheries resources in a context of multiple objectives, stakeholders and uncertainties. In order to achieve sustainability through an integrated management policy, this strategy is constituted by nine iterative and interactive steps: data collection, processing, analysis, communication, deliberation, decision, action, evaluation and adaptation. Those steps are the main components of the production and the use of any system of indicators.

Keywords: indicators, fisheries, sustainability, management

INTRODUCTION

The exploitation of the marine resources is a significant source of economic and social development. According to FAO [3], fishing is an important activity in the world and it contributes to the subsistence of hundreds of millions of people. These socio-economic aspects are the main stakes that lead to a quick and generalized exploitation of the fisheries resources during the 20th century. Taking into account the huge world demand of fisheries products, the world fisheries has become quickly dynamic through significant investments in flotillas, fishing material and modern factories of transformation in order to benefit from the important economic potentialities of the biological marine resources. However, it appeared that those resources which are renewable but not infinite cannot support an uncontrolled intensification of their exploitation. The overexploitation of many fish stocks and the destruction of the marine ecosystems threaten the sustainability of the world fisheries. So they have to be rationally managed in order to maintain their contribution to the human wellbeing [2, 3]. In Senegal, considering the highly strategic role of the fisheries, the threats on the marine resources has become a great concern which explains the particular attention expressed by the mains stakeholders (administrations, scientists, NGO, fishermen and consumers) for a rational management of those resources [23]. In this context, this paper is a contribution for a better understanding of the interactions between the ecological factors and the socioeconomic aspects of the Senegalese fisheries. The ideas developed here constitute an attempt to provide a tool for management of the fisheries sustainability.

GENERAL STRUCTURE OF THE SYSTEM OF INDICATORS

Pressure-State-Response approach to select a set of indicators

Designed by OECD [15], the PSR (Pressure-State-Response) approach is largely popularized by many authors. It is used to identify a set of indicators taking account the causes (pressure), the effects (state) and the actions to be undertaken to solve environmental and ecological problems. This approach is based on the following principle: the human activities exert pressures on the environment and the natural resources being able to induce changes of their state which requires decisions and actions (societal response) aiming to prevent, reduce or correct the pressures and/or the damages related to the changes of state. The societal response closely depends on the availability of synthetic information (a set of indicators) on the pressure and the state. In order to satisfy this requirement, the set of indicators proposed here is based on the link between the fishing activities which represents de pressure and their impacts considered here as the ecological and socioeconomic state.

About the selected indicators

The fishing activities correspond to two groups of indicators relating to the fishing effort and the catch that respectively measure the intensity of the fishing activities and the level of resources extracted from the marine ecosystems. The specific indicators of effort are selected by taking account the main fishing techniques (gears) of the artisanal and industrial fisheries. In the case of artisanal fisheries, the effort corresponds to the total number of trips done by canoes using hand lines, gillnets and ring nets. The artisanal catch is regrouped according three types of resources (pelagic fish, demersal fish and others species like cephalopods, mollusks and crustaceans). For the industrial fisheries, the fishing activity refers to the number of days at sea and the corresponding catch done by bottom trawl. The data used to determinate all the indicators mentioned above come from the database of the Centre for Oceanographic Research of Dakar-Thiaroye in Senegal [23].

The ecological state is measured by three groups of indicators relating to the abundance, the length and the trophic level of the catch. The catch per unit of effort (cpue) of the main species (*Sardinella aurita, Sardinella madarensis, Pagellus bellottii, Sparus caeruleotictus, Epinephelus aeneus, Cynoglossus spp* and *Cymbium spp*) are chosen as abundance index. To ensure that those cpue represents well the abundance, for each species a specific gear that targets it is chosen. For all of these main species mentioned above the average lengths are calculated except *Cynoglossus spp* and *Cymbium spp* for which data are not available. Data used for the cpue and the lengths are also available in the database of the Centre for Oceanographic Research of Dakar-Thiaroye. The average trophic level is calculated using 130 species clearly identified in the catch [23]. Data about trophic level are mainly extracted from the online FishBase database. But for few species, complementary data come from Laurans et al. [10]. This formula is used to estimate the average trophic level (eq. 1):

$$\overline{TL}_k = \frac{\sum_{i=1}^{N} Y_{ik}\, TL_i}{\sum_{i=1}^{N} Y_{ik}} \qquad \text{(Eq. 1)}$$

where Y_{ik} corresponds to the total catch for species i at the year k and TL_i its trophic level. N is the total number of species taken into account (here $N = 130$).

The socioeconomic fisheries state is analyzed through some indicators that represent the role of the fisheries in the satisfaction of the main economic and social needs. We first estimate the economic yields of five main target species by multiplying the average landing prices expressed in Franc CFA (FCFA) which is the national currency of Senegal, by the abundance index. Those economic yields represent the average amount that can be provided by each target species during a trip. It’s important to note that they don’t correspond to the fishing revenues because they do not take account the fishing costs for which time series are not available. We also use the total gross domestic product (GDP) of the fisheries. It is estimated by the Office of the National Accountancy of the National Agency for Demography and Statistics of Senegal. The amount of currency (in US$) provided through the importations is also considered as an economic state indicator. This indicator is obtained through the electronic database of

FAO. In the case of social aspects, generated employment is taken into account through the number of people directly working in the fisheries sector. We also consider the national average consumption (per capita) of fisheries products as an indicator of social fisheries state. It enables us to examine the importance of fisheries for food safety. This indicator is estimated by dividing the total consumption of fisheries products by the total Senegalese population. The data of total consumption are provided by the Direction of Marine Fisheries. It takes only account the fresh products. The total population is available through the census and estimations regularly done by the National Agency for Demography and Statistics.

The table below (table I) shows the main characteristics of the set of fisheries sustainability indicators selected. Our objective is not to provide an exhaustive set of indicators. Taking account the availability and the relevance of data required for fisheries sustainability management, we propose a list of basic indicators which can help us to show why and how to simultaneously consider both ecological and socioeconomic dimensions in the fisheries management process. The list proposed here comprises similarities with the FAO directive on indicators for sustainable development of marine fisheries [3]. It also contains many variables used in the RAPFISH tool for comparative evaluation of fisheries sustainability [17].

Table I: List of indicators selected for fisheries sustainability

Categories of indicators	Codes of indicators	Label of indicators	Unit of indicators
Fishing Activities Pressure	effhdl	Effort of hand lines	Trips
	effgnt	Effort of gillnets	Trips
	effrnt	Effort of ring nets	Trips
	effbtr	Effort of bottom trawl	Days
	catpel	Artisanal pelagic fish catch	Tonnes
	catdem	Artisanal demersal fish catch	Tonnes
	catoth	Other artisanal species catch	Tonnes
	catbtr	Industrial bottom trawl catch	Tonnes
Fisheries Ecological State	aisaur	Abundance index of *Sardinella aurita*	Kg/trip
	aismad	Abundance index of *Sardinella madarensis*	Kg/trip
	aipbel	Abundance index of *Pagellus bellottii*	Kg/trip
	aiscae	Abundance index of *Sparus caeruleotictus*	Kg/trip
	aieaen	Abundance index of *Epinephelus aeneus*	Kg/trip
	aicymb	Abundance index of *Cymbium spp*	Kg/trip
	aicyng	Abundance index of *Cynoglossus spp*	Kg/trip
	lgsaur	Average length of *Sardinella aurita*	Centimeter
	lgsmad	Average length of *Sardinella madarensis*	Centimeter
	lgpbel	Average length of *Pagellus bellottii*	Centimeter
	lgscae	Average length of *Sparus caeruleotictus*	Centimeter
	lgeaen	Average length of *Epinephelus aeneus*	Centimeter
	TL	Average trophic level of the catch	Level
Fisheries Socioeconomic State	eysaur	Average economic yield of *Sardinella aurita*	FCFA/trip
	eysmad	Average economic yield of *Sardinella madarensis*	FCFA/trip
	eypbel	Average economic yield of *Pagellus bellottii*	FCFA/trip
	eyscae	Average economic yield of *Sparus caeruleotictus*	FCFA/trip
	eyeaen	Average economic yield of *Epinephelus aeneus*	FCFA/trip
	gdp	GDP generated by the fisheries	10^9 FCFA
	curr	Currencies provided by the fisheries	US$
	empl	Employment provided by the fisheries	10^3 persons
	cons	Average consumption of fisheries products	Kg/person

STATISTICAL METHODS TO ANALYZE THE SYSTEM OF INDICATORS

Principal Components Analysis to describe multivariate correlations

When measuring only two variables, it is easy to plot the data and visualize the correlations between these two variables. In the case of several variables, it becomes difficult to visualize the correlations. One of the methods that can help to reach this objective is to reduce the dimension. Principal Components Analysis (PCA) is among the possible techniques that reduces the data into two dimensions. Such a reduction is done by extracting the directions (called principal components) where the cloud of values is more extended. A principal component is a linear combination of optimally-weighted observed variables. In the case of our analysis where we have a time series data set each principal component constitutes a time series which summarize the evolution of the indicators correlated with it.

Empirical standardization to represent fisheries sustainability profiles

One of the main goals of a system of indicators is to visualize at any time the profile of a given phenomenon. Because of the diversity and heterogeneity of the various indicators it is essential to standardize them. The choice of a standardization method is arbitrary. However, it is preferable that the reference values chosen for standardization reflect the objectives of the societal response (situations to reach or to avoid). The standardization method chosen in this paper is empirical. In this method, reference levels of each given indicator correspond to its minimum and maximum values during the considered period [14]. Thus, those values are respectively associated to 0% and 100%. The intermediate values are then calculated by the following formula (eq. 2):

$$I'_t = \frac{I_t - I_{min}}{I_{max} - I_{min}} \qquad \text{(Eq. 2)}$$

where I_t and I'_t represents respectively the real value and the standardized value of a given indicators *I* at the time *t*. I_{min} and I_{max} are the minimum and maximum values during the considered period. Once the standardization done, the set of indicators can easily be represented through radar graph also known as web chart [17, 14].

Hodrick-Prescott filter to estimate the trends of the indicators

There are several methods to estimate the trend of a given time series. Many of them are based on modeling techniques by supposing that the data are linked to the time through a mathematical relationship. But there are other robust methods more adapted local adjustment. That is the case of Hodrick-Prescott filter [5]. This nonparametric smoothing method is usually used to estimate the long-term trends of many macroeconomic indicators [18, 7, 4]. To estimate the trend T_t of a given indicator I_t Hodrick and Prescott proposed a filter that consists to solve the problem of minimization below (eq. 3):

$$\underset{\{T_t\}_{t=1}^{n}}{Min} \left[\sum_{t=1}^{n} (I_t - T_t)^2 + \lambda \sum_{t=2}^{n-1} [(T_{t+1} - T_t) - (T_t - T_{t-1})]^2 \right] \qquad \text{(Eq. 3)}$$

where *n* is the total number of time units (in particular the number of years) of the time series. For very high values of λ, the trends estimated are almost linear but the smoothing residuals are more important. Very low values of λ give trends that are almost identical to the initial time series. The choice of λ depends on the arbitration between the objective of a perfect smooth and the concern of taking account some local characteristics of the time series. This flexibility is the real advantage of this method.

Mann-Kendhal test to describe the trends of the indicators

Once a trend estimated, it should be important to attest its significance by using robust statistical techniques. One of the most known techniques is the Mann-Kendhal test [13, 8] that is usually used to describe the significance and the direction of the trend [16, 22]. It is a nonparametric test which is not affected by the extreme values (outliers). Its use is however more effective for monotonous trends. The principle of the test whose algorithm is described below consists on comparing all the values of the trend.

For $i < j$ calculate the statistic of the test (eq. 4):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} s_{ij} \quad \text{where} \quad s_{ij} = \begin{cases} +1 & \text{if } T_i > T_j \\ 0 & \text{if } T_i = T_j \\ -1 & \text{if } T_i < T_j \end{cases} \qquad \text{(Eq. 4)}$$

In practice, the test is performed by using the standardized statistic defined by (eq. 5):

$$Z = \begin{cases} \frac{S-1}{\sigma_S} & si\ S > 0 \\ 0 & si\ S = 0 \\ \frac{S+1}{\sigma_S} & si\ S < 0 \end{cases} \quad \text{where} \quad \sigma_S = \sqrt{\frac{n(n-1)(2n+5)}{18}} \qquad \text{(Eq. 5)}$$

This standardized statistic follows the standard normal distribution. Thus if $|Z| \geq u_{\alpha/2}$ the null hypothesis is rejected, that means the presence of a significant monotonous trend. A threshold of $\alpha/2$ equal to 5% is retained for all the tests carried out in this paper. Once a significant trend is statistically attested by the test, its direction is given by the sign of *Z*. If $Z<0$ the trend is decreasing and for $Z>0$ the trend is increasing. A robust estimation of its slope (not affected by the outliers) can then be done through this formula (eq. 6) proposed by Sen [21]:

$$\beta = Médiane\left(\frac{T_j - T_i}{j-i}\right) \qquad \text{(Eq. 6)}$$

ANALYSIS OF THE SYSTEM OF INDICATORS

Interpretation of the multivariate correlations

In the PCA figure (fig. 1), we can see through the histogram of eigenvalues that the three first components (C1, C2 and C3) summarize 71% of total inertia of the set of indicators. So in our analysis, emphasis will be put on them. With 44% of the total inertia, the first component C1 constitutes a good synthesis of the global evolution of the majority of the indicators. It characterizes the indicators whose general evolution is monotonous (increasing or decreasing). There is a clear opposition of two great groups of indicators. The first group which is constituted by increasing indicators is negatively correlated with C1. Those indicators are also strongly correlated between them. This group characterizes the development of the fishing activities (effort and catch) which has positive socioeconomic impacts. Those socioeconomic impacts are perceptible through the increasing of some indicators such as economic yields, fisheries GDP, currencies, employment and consuption of fisheries products. The second group which is positively correlated with C1 represents the decreasing indicators. It includes the indicators of ecological state. The decrease of those indicators means a progressive degradation of the ecosystem health resulting to the sustained expansion of the fishing activities during the last two decades. That ecological deterioration is emphasized by the worsening situation of the abundance index (in particular for the demersal fish), the avarage lengths and average trophic level of the catch.

The two others components (C2 and C3) highlight the particular indicators whose evolution is not monotonous. C2 represents indicators that are relatively sinusoidal such as the average length of *Pagellus bellottii*, while C3 describes parabolic situations (case of the average length of *Sardinella aurita* and the abundance index of *Sardinella aurita* and *Sparus caeruleotictus*).

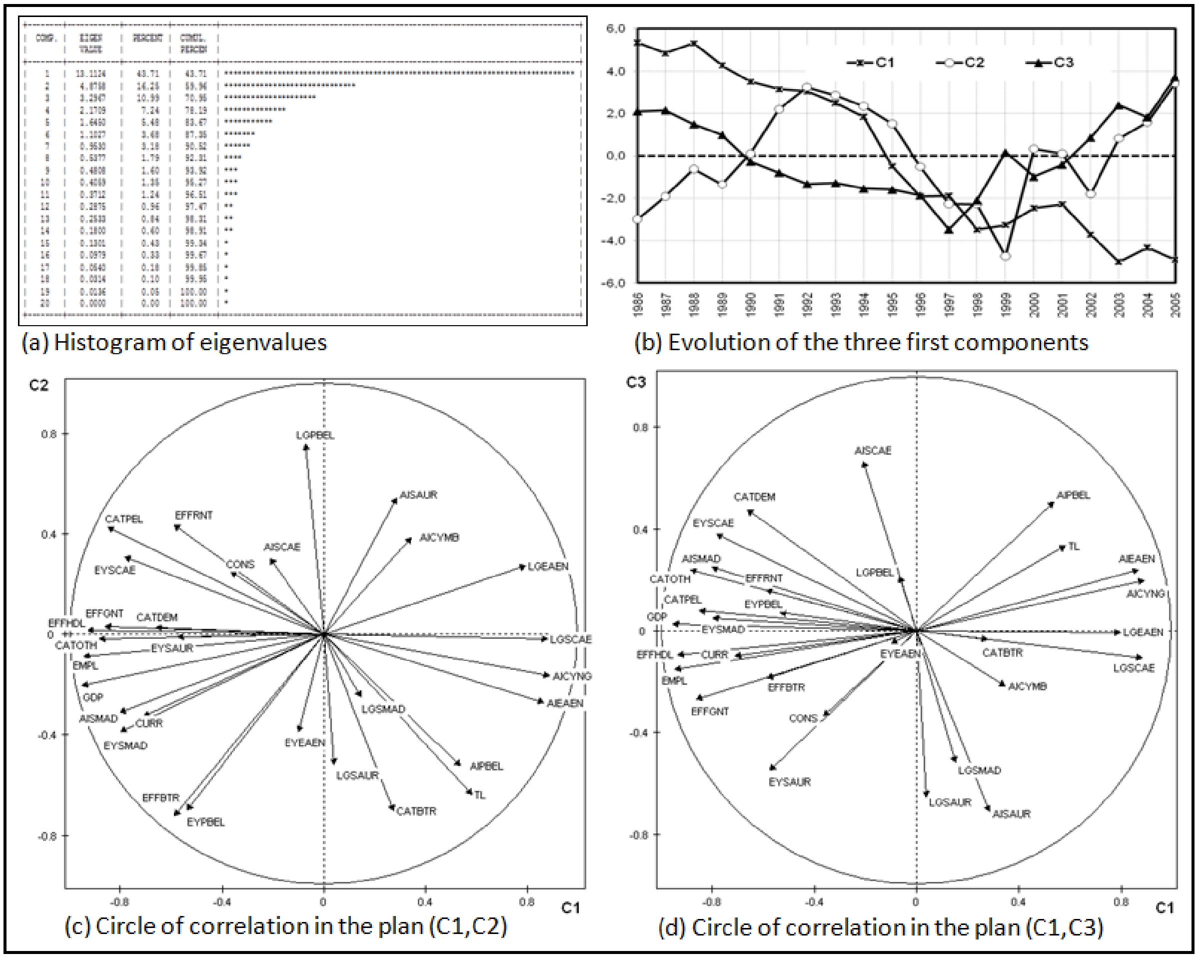

Figure 1. Multivariate correlations between indicators of fisheries sustainability

The negative correlations between the two main groups of indicators express the conflicting interactions between ecological and socieconomic dimensions of the fisheries. This situation is the reflect of the antagonism between fisheries development and marine ecosystem health. This dilemma between the conservation and the exploitation of natural resources is the real problem faced in the management of fisheries sustainability. The purpose to maintain a minimal stock of natural ressources for intergenerationnal needs is strongly liable to the simultaneous mastery of highly dynamic and multivariate factors. Thus the management of fisheries sustainability faces the main problem of dynamic co-viability between ecological and socioeconomic systems [11, 1].

Global overview on the profiles of the fisheries sustainability

The representation of the standardized values is suitable to give an overview of the profiles of the fisheries sustainability at any given time. Indeed, this kind of graph shows the relative position of each indicator compared its extreme values (minimum and maximum). So at any given time an appreciation can be given on the level of degradation (or improvement) of each indicator. The comparison of several situations at different dates enables to better understand the changes that progressively affect the fisheries. In the case of Senegalese fisheries, the visualisation of five different profiles separated by five years (fig. 2) reveals significant changes which gradually occurred in the fisheries.

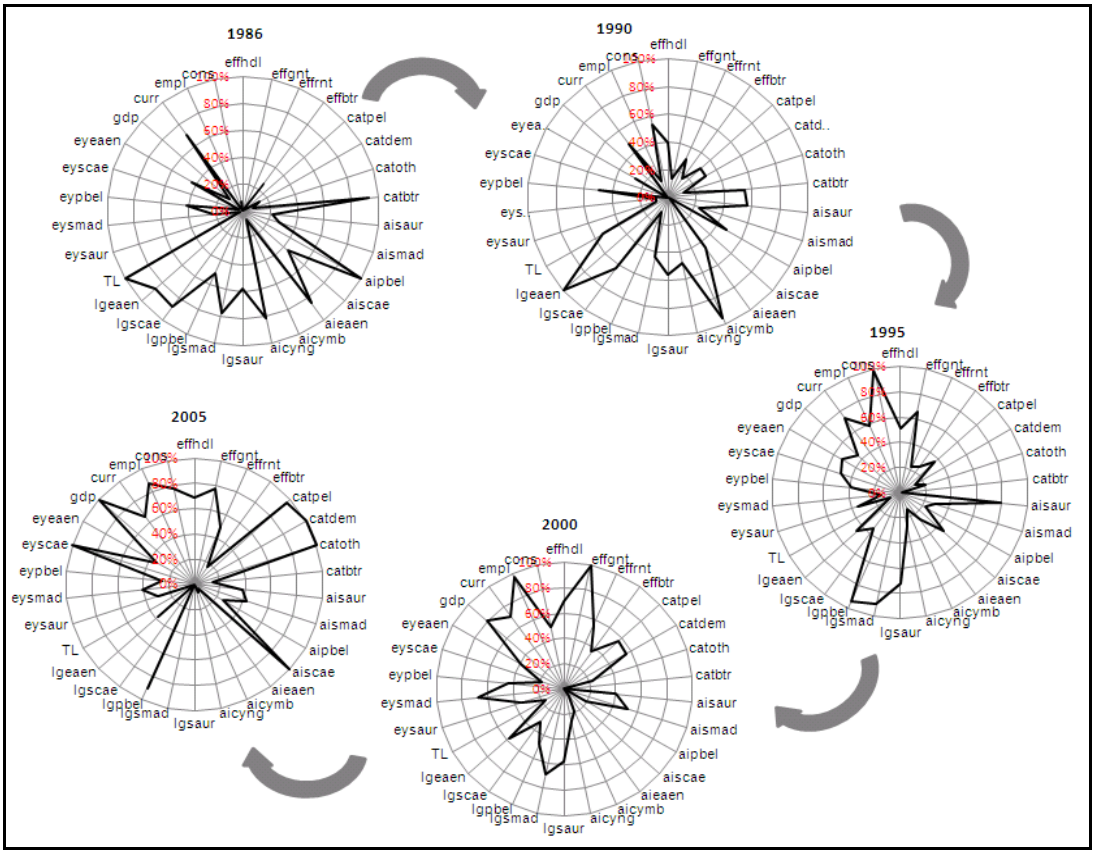

Figure 2. Web charts of five profiles of the fisheries sustainability

In 1986 the standardized values of ecological indicators which are between 80% and 100% show a rather good ecological situation. However, during the following years the ecological indicators (abundance index, lengths and trophic level) are globally worsening while the fishing activities and the socioeconomic indicators progressively tend towards higher levels. It is important to notice that in 1995 the profile seems to present a relative balance between the different categories of indicators. In 2000, the profile is rather characterized by a clear deterioration of the ecological state. Indeed, execpt the abundance index of *Sardinella aurita* and *Sardinella madarensis* whose standardized values hardly reach 50%, the ecological state is in a very low level (standardized values ranging between 0% and 25%). In opposite, this deterioration of the ecological state that results from a higher fishing pressure corresponds to a better situation for the socioeconomic state whose most indicators post standardized values higher than 50%. In 2005, except the improvement of the abundance index of *Sparus caeruleotictus* and the average length of *Pagellus bellottii*, it clearly appears that the ecological state is in a very bad situation. Contrary to the ecological state, the socioeconomic indicators rather show very high levels except for some economic yields that seems be lower compared to the situation in 1995.

Lessons from the trajectories of the indicators

In order to have a dynamic vision on the fisheries sustainability it is important to get more details on the global trajectories of the different indicators. The determination of the trends through the Hodrick-Prescott filter (with λ=100) is the approach we use to reach this goal (fig. 3). For each indicator, the trajectory is represented through a graph combining the original values (full line) and the estimated values of the trend (broken line). Moreover, the estimated slope whose sign and absolute value inform about the nature and the importance of the trend is posted. In the particular cases where the Mann-Kendhal test concludes to a non-significant trend, we mention that the trend is non-monotonous.

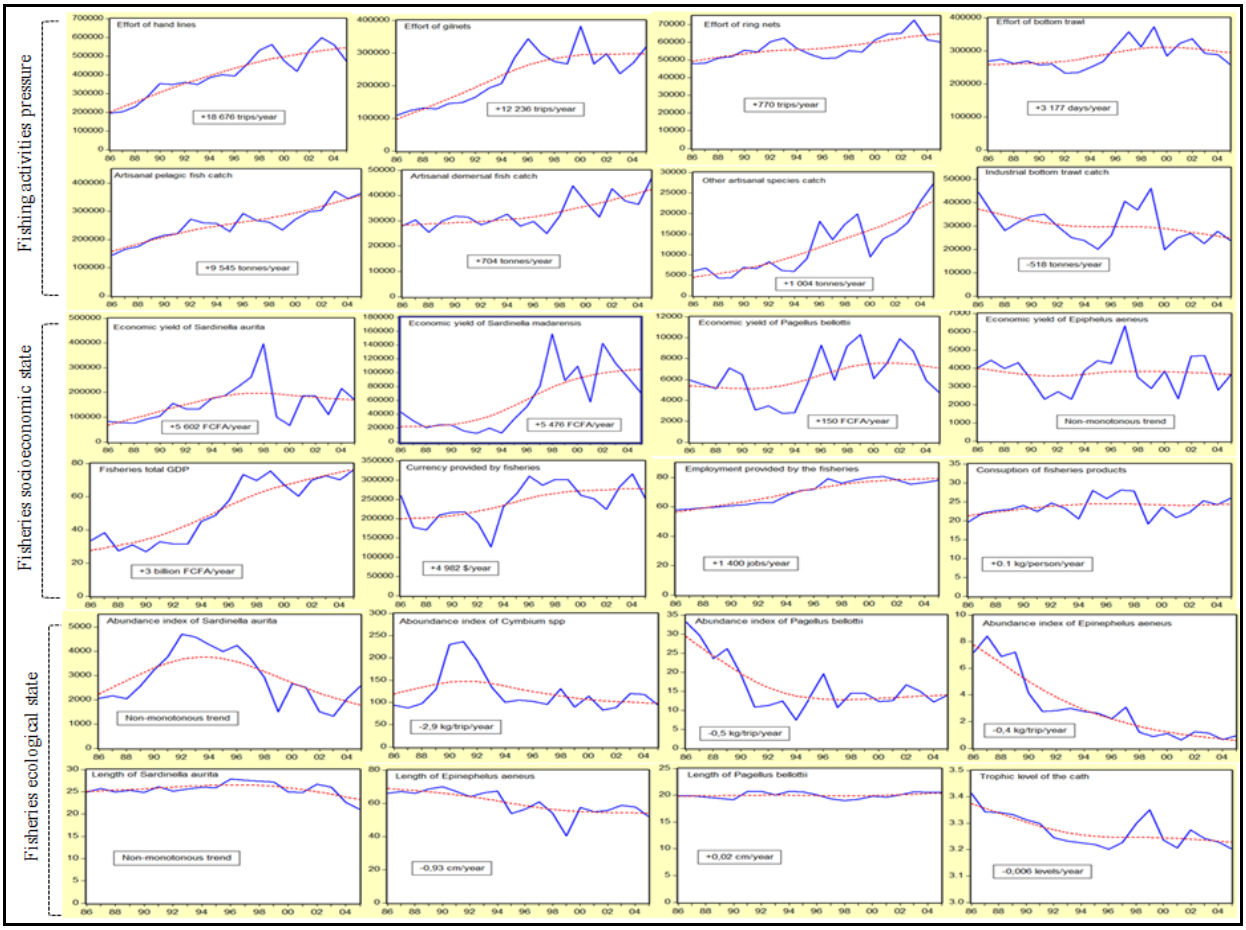

Figure 3. Trajectories of the indicators of fisheries sustainability

Through the figure above we can see that except the catch of the bottom trawl which is decreasing (-518 tonnes/year), all the indicators of fishing activities present increasing trends. The fishing effort of the hand lines and gillnets are characterized by a strong increase with an annual average growth reaching respectively 18 676 trips/year and 12 236 trips/year. However, after a very quick raise of the trends the fishing efforts of those two fishing gears are relatively stabilized since the end of the nineties. The slope of the fishing effort of the ring nets is less significant but remains considerable (+770 trips/year). Moreover, instead of stabilization, the effort of ring nets is rather characterized by a continuous growth during the whole period 1986-2005. The trajectory of the fishing effort of the bottom trawl is characterized by two phases with moreover an annual growth of 3 177 days. Since the beginning of the period, the progression is rather high until the end of the nineties. Then after reaching a highest level around 300 000 days, the fishing effort of the bottom trawl seems to start a progressive fall. Regarding to the catch, we can note the great dynamism of the artisanal fisheries. Indeed, contrary to the bottom trawl whose catch is in decrease, the trends of the artisanal fisheries catch is characterized by a growth. Thus for the pelagic fish catch, the slope is very high (+9 545 tonnes/year). In the case of the demersal fish (+704 tonnes/year), after being marked by a relative stability the catch knew a considerable increase starting from the second half of the nineties. With the rarefaction of the most target demersal species this increase is mainly due to the intensification of the exploitation of new target species like *Arius spp* whose important quantities are currently landed.

The indicators of socio-economic state are all marked by increasing trends. But at the beginning of the period, the levels of those indicators were very low and relatively stable until the beginning of the nineties. Starting from 1994, a particular period that affected all those indicators is noted. During this year, the 50% devaluation of the FCFA (national currency) had positively impacted the prices of the majority of the target species particularly those which are exported. This impact has involved a quick and high increase of the economic indicators. With quite similar levels, the economic yields of *Sardinella aurita* and *Sardinella madarensis* are characterized by important growth rate between 1986 to 2005 (respectively +5 602 FCFA/year and +5 476 FCFA/year). Concerning *Pagellus bellottii*, the growth rate is rather less important (+150 FCFA/year). Except *Epinephelus aeneus* for which the global trend is relatively stationary in the whole period with few fluctuations, the economic yields of the main target species are rather stable and even decreasing since the end of the nineties. The particular situation of *Epinephelus aeneus* can be explained by the fact that the price is such higher and higher to compensate the strong decrease of its abundance. In the particular case of the generated GDP and the amount of provided currencies by the fisheries, the levels of the slopes are also very significant (respectively +3 billion FCFA/year and +4 982 US$/year). The employment is also considerable with around 1 400 new jobs created per year. It is important to note that with around 60 000 fisherman currently, the artisanal fisheries are essentially the provider of those jobs. The consumption of fisheries products is also increasing but rather in moderate way (+0.1 kg/person/year). It seems to be stable since the end of the nineties.

Contrarily to the economic state whose trajectories are globally increasing, the situation of the ecological state is rather in deterioration. Indeed, most of the trends of the indicators of ecological state are characterized by negative slopes. This decrease is more perceptible for the abundance index of *Epinephelus aeneus* and *Pagellus bellottii* (respectively -0.4 kg/trip/year and -0.5 kg/trip/year), the length of *Epinephelus aeneus* (-0.9 cm/year) and the trophic level (-0.006 levels/year). It is important to mention that for the particular case of the trophic level very little variations can have very important ecological consequences. With an annual decrease of 2.9 kg/trip, the trend of the abundance index of *Cymbium spp* is marked by two steps. Before the beginning of the nineties, the abundance index knew a very quick and high growth. After reaching a maximum level around 230 kg/trip, the abundance index began to fall down starting from the second half of the nineties. This kind of trajectory is also quite similar for the abundance index and the length of *Sardinella aurita*. Indeed, in spite the fact that the trends of these two indicators are not statistically significant (non-monotonous trends), we can note that since the middle of the nineties, the situation of *Sardinella aurita* seems to be in deterioration. With a relative stability around 20 cm the length of *Pagellus bellottii* seems to be relatively in better situation.

MANAGING FISHERIES SUSTAINABILITY THROUGH A SYSTEM OF INDICATORS

A system of indicators as a medium for communication

In the context of new paradigm of governance where transparency and participation are required, communication has become an essential element in any management process. In the particular case of sustainability management, the necessity of communication is above all justified by the fact of multiplicity of stakeholders that need sufficient and reliable information to better understand the stakes and challenges to be faced in order to find suitable strategies. By enabling multiple stakeholders to enrich their representation and their comprehension of the complexity to be faced, a system of indicators enables them to better express their point of view and interact between them. Structured on a set of multidimensional and interdependent indicators, the system of indicators is enough convenient to help stakeholders to better understand and discuss about the constraints of fisheries sustainability management. Through the different possibilities to present various data (tables, multivariate correlations, web charts, trends …) a system of indicators offers a relative flexibility in the manner of exposing the stakes and the constraints of the fisheries sustainability management. It makes it possible to present periodically an assessment on the situation of the fisheries by taking account both ecological and socioeconomic dimensions. Thus a system of indicators can be a suitable medium which takes into account the three main roles of a communication process in the particular case of natural resources management [19]:

- to ensure the understanding by the treatment and the interpretation of information,
- to encourage the research activities and the acceptance of the undertaken policies;
- to facilitate exchanges and negotiations between various stakeholders.

A system of indicators as a platform for deliberation

Communication is essential for natural resources management. But stakeholders should not only be reduced to simple passive receptacles of information. In this fact, beyond the role of providing synthetic information the system of indicators should also help all the stakeholders to identify constraints and find suitable solutions taking account the ecological, economic and social stakes. Indeed, in a natural resources management process it is really complex to find a dynamic balance between the societal needs and the ecosystem health in order to ensure the right of the future generations to benefit from those resources. The need to find suitable and acceptable solutions involves the necessity to set up a deliberation framework. It is a collective process during which several possible solutions are compared according to their respective advantages and disadvantages. A deliberative process aims to encourage co-operation, participation, transparency and responsibility for the search of the most acceptable solutions by various stakeholders having different and even conflicting interests. It requires a principle of dialogue which supposes the existence of a platform where the problems are clearly presented in order to guide the choices of all the stakeholders. In this fact a system of indicators that enables to present many details of a problem can constitute a considerable contribution for fisheries sustainability management. Thus consensual diagnosis that can be done through the system of indicators must facilitate the search of the measurements to be undertaken to improve the ecological state without involving harmful socioeconomic impacts. Such a participative strategy aims to reinforce the legitimacy of the decisions.

A system of indicators as a tool for adaptative management

According to the complexity of the fisheries stakes the production and the use of indicators should be the main pillars of the fisheries sustainability management (fig. 4). The production of the indicators includes the steps of data collection, processing and analysis. The information obtained through these three steps enable to feed the communication on the fisheries situation. Once all the stakeholders are aware of that situation, the deliberation step has to be organized to examine all possible solutions to ensure sustainability. If during the deliberation the stakeholders think that the available data are not sufficient or reliable enough for a suitable decision the production of complementary data can be recommended. That principle involves a possible come back to the data collection step. On the other hand, if the available data give a good understanding which makes it possible to find suitable solutions, then the deliberation leads to a final decision on the measurements to undertake in order to solve the identified problems. This step, which is only a theoretical commitment, must be followed by a practical implementation through concrete actions whose effectiveness has to be evaluated. Thus the evaluation step enables to assess the results of the actions and identify the potential difficulties to achieve expected objectives. All the results of that assessment must be communicated to the stakeholders who can reiterate a new deliberation. As a participative step the deliberation is the heart of the process. However, as a crown the adaptation enables to ensure the continuity of the process. It consists in bringing permanently corrective recommendations that make it possible to improve the effectiveness of the production and the use of the indicators in order to guarantee the adequacy between management policies and the evolution of the fisheries situation. The fact to take account the principle of adaptation corresponds to what is called adaptive management.

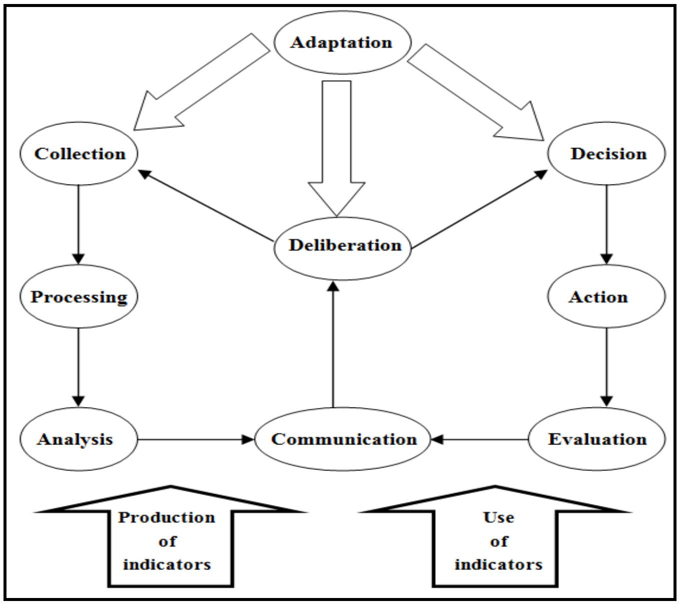

Figure 4: Indicators for adaptative management

In the field of the natural resources and environment, adaptive management is essential because there are many uncertainties that can affect the effectiveness of undertaken policies [20]. Moreover, in the particular case of fisheries management, the functioning of marine ecosystems is such complex that available knowledge are not generally sufficient enough to provide with certitude suitable responses to solve the problems relating to their exploitation. Thus, by ignoring those uncertainties, undertaken management policies can cause more environmental degradation, loss of ecological services and economic and social instabilities [25, 24].

The paradigm of adaptive management is based on a simple principle: any result (success or failure) of a policy constitutes a lesson for better refining the strategy later on. It recognizes explicitly the existence of uncertainties and gaps in knowledge relating to the functioning of complex systems and the measurements undertaken to manage them [12]. Through the monitoring of the situation, new acquired knowledge should encourage to make modifications in the management plan [20]. Adaptive management is thus a learning by doing approach which must be based on dialogue and interdisciplinary [6, 25].

CONCLUSION

Through this case study we have tried to show that a suitable system of indicators can be very useful for the understanding of socioeconomic and ecological interactions and the management of fisheries sustainability. Based on PSR (pressure-state-response) approach the diagnosis made on the Senegalese fisheries enables to stress on their complexity and great changes that affected them. Indeed, we have seen that the fishing activities are very important for the improvement of socioeconomic state. But in the other hand they constitute a considerable pressure whose long-term consequences involve ecological degradation. Thus in order to overcome those conflicting interactions and ensure sustainability, a suitable societal response must permanently aim a dynamic balance between human needs and marine ecosystem health. Being able to provide a global overview on fisheries situation, a system of indicators is useful as a dashboard for sustainability management. Such a system of indicators which however requires the exploration of various databases is essential to expose the main stakes and support a participative management in a multi-stakeholders context. It is a tool that can facilitate a collective identification and comprehension of the problems in order to guarantee consensus and acceptability for the implementation of undertaken measurements. In this fact, we think that a system of indicators should be more effective if it is inserted in a global adaptative management process which enables to reduce progressively the multiple uncertainties affecting all the steps of that process.

REFERENCES

[1] Cury P. et al, 2005. Viability theory for an ecosystem approach to fisheries. In Daan N., Christensen V. and Cury P., 2005. Quantitative ecosystem indicators for fisheries management. *ICES Journal of Marine Science* 62(3), pp. 577-584.

[2] FAO, 1995. Code of conduct for responsible fisheries. 41 p.

[3] FAO, 1999. Indicators for sustainable development of marine capture fisheries. *FAO Technical Guidelines for Responsible Fisheries* 8, 68 p.

[4] Gómez V. and Bengoechea P., 2000. The quarterly national accounts trend-cycle filter versus model-based filters. *Spanish Economic Review* 2, pp. 29-48.

[5] Hodrick, R. and Prescott, E.C., 1980. Post-War U.S. Business Cycles: An Empirical Investigation. Mimeo, Carnegie-Mellon University, Pittsburgh, P.A.

[6] Holling C. S., 1978. Adaptative environmental assessment and management. *John Wiley*, New York.

[7] Kaiser R. and Maravall A., 1999. Estimation of the business cycle: A modified Hodrick-Prescott Filter. *Spanish Economic Review* 1, pp.175-206.

[8] Kendall M. G., 1975. Rank Correlation Methods, Griffin, London.

[9] Laloë F., 2007. Information at the interface between supply and demand for indicators: The use of a model with estimated parameter values as a base for indication in multi criteria analysis. *International Journal of Sustainable Development* 10(1/2), pp. 33-45.

[10] Laurans M. et al., 2004. Changes in the trophic structure of demersal fish communities in West Africa in the three last decades. *Aquatic Living Resources* 17, pp. 163–173.

[11] Le Fur et al., 1999. Co-viabilité des systèmes halieutiques. *Natures Sciences Sociétés* 7(2), pp. 19-32.

[12] Lee K. N., 1993. Compass and gyroscope: integrating science and politics for the environment. Washington D.C., *Island Press*.

[13] Mann. H. B., 1945. Nonparametric tests against trend, *Econometrica* 13, pp 245–259.

[14] Munda G., 2005. Measuring sustainability: a multi-criterion framework. *Environment, Development and Sustainability* 7, pp. 117-134.

[15] OECD, 1993. OECD Core set of indicators for environmental performance reviews, 39 p.

[16] Onoz B. and Bayazit M., 2003. The power of statistical tests for trend detection. *Turkish Journ. Eng. Env. Sci.* 27, pp 247-251.

[17] Pitcher T. J. and Preikshot D., 2001. RAPFISH: a rapid appraisal technique to evaluate the sustainability status of fisheries. *Fisheries Research* 40, pp. 255-270.

[18] Razzak W., 1997. The Hodrick-Prescott technique: A smoother versus a filter: An application to New Zealand GDP. *Economics Letters* 57, pp. 163–168.

[19] Röling N., 1994. Platforms for decision-making about ecosystems. In Fresco L. O. et al., 1994. The future of the land: mobilizing and integrating knowledge for land use options. *John Wiley & Sons Ltd*, pp. 385-393.

[20] Ruddle K. and Hickey F. R., 2008. Accounting for the mismanagement of tropical nearshore fisheries. *Environ. Dev. Sustain.*10, pp. 565-589.

[21] Sen P. K., 1968. Estimates of the regression coefficient based on Kendall's tau'. *Journ. of Americ. Statist. Assoc.* 63, pp.1379–1389.

[22] Sheng Y. and Chunyuan W., 2004. The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resources Management* 18, pp. 201–218.

[23] Thiao D., 2009. Un système d'indicateurs de durabilité des pêcheries côtières comme outil de gestion intégrée des ressources halieutiques sénégalaises. PhD Thesis in Economics (Integrated Sustainable Development), Université de Versailles Saint-Quentin-en-Yvelines, France, 297 p.

[24] Walters C. J. and Holling C. S., 1990. Large scale management experiments and learning by doing. *Ecology* 71, pp. 2060-2068.

[25] Walters C. J., 1986. Adaptative management of renewable resources. New York, McMillan.