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Analyzing fish stocks dynamics using CPUE and PRCF: a new approach for the fishery management

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PEER REVIEW

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Comments

This is a good writing paper. The study explored a new method combined with CPUE and PRCF to assess the state of exploited fish stocks and discussed whether the potential impact of population dynamics of fish stocks relate with endogenous or exogenous factors.
Details on Page 5

ABSTRACT

Catch per unit effort has been used in many fisheries researches worldwide like an abundance or density index. Parallel to this issue, partial ratio correlation function is a technique used to identify the density dependent structure underlying ecological time series. Although partial ratio correlation function is widely used in ecological fields, it has not been much used in fisheries and aquatic sciences. In this synthesis, a new combination of statistical techniques is proposed to diagnose the order of the population dynamic of fish stocks, as the first knowledge of the type of factors that may be regulating them, included human predation as an exogenous factor.

KEYWORDS

CPUE time series, Density-dependence, Fishery management

1. Introduction

From the last twenty years, fishery scientists around the world have been required to provide regular advice to fishery managers based on biological assessments of the state of exploited fish stocks[1]. Furthermore, the management and conservation of the world's oceans require synthesis of spatial data on the distribution and intensity of human activities. Moreover, the long-term objectives for fisheries management should be taken into consideration in scientific fishing research and population dynamics, as well as the climatic changes that may affect the stocks[2,3]. In addition, the role of climate on the abundance and distribution of species is one of the most basic exogenous factors affecting populations, including fish stocks[4-8]; despite the doubts raised by meteorologists′ and oceanographers′ uncertainties supporting marine ecosystems and fisheries. However, what scientists are entitled to do is to try to identify key processes impacting marine fisheries and ecosystems with a comparable scientific basis[9]. So that fisheries activity destroys the structural integrity of marine food webs and magnifies fluctuations in fish stock abundances, because age-truncated populations have more variable dynamics that may destabilize the biomass flow in the marine size spectrum with their corresponding consequences for fisheries management[10-12]. Besides, the impact on fisheries of changes in the biological productivity of marine ecosystems can vary between fisheries and can depend of the specific environmental changes that occur and the particular biological characteristics of each species[13]. Therefore, ecology-based approaches are required to try to mitigate the damage caused by fishing[9]. In contrast,

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nowadays, between ecological and fishery scientific researches, we can find several studies that have used time series to explain trends in biodiversity and fisheries[14-19], attached to the effects of climate on fish population dynamics[6-8], as well as studies of the same nature, based on abundance time series data that include atmospheric variables[20-23]. But few have employed catch per unit effort (CPUE) time series, as abundance index, together to partial rate correlation function (PRCF) to try to identify the causes of the population fluctuations in fishes as the interaction between endogenous and exogenous factors[24,25]. So, what can scientists do to get a previous knowledge about the causes of fish population fluctuations? In other words, how can scientists diagnose the order of the population dynamic of fishery resources? First of all, it is necessary to understand which kind of factors is related with the population fluctuations of these resources for a later evaluation of different models. Thus, the aim of this paper is to propose the integration of CPUE time series-as abundance time series-into a PRCF analysis to get information about the population dynamic order of each stock exploited.

2. CPUE time series

In abundance time series analysis, it might be interesting to determine the structure of the density dependent on feedback processes; as a result, this can lead to important inferences about the factors involved in population regulation[26,27]. The recognition of CPUE as an index of abundance has been revisited[28,29], because CPUE has been widely used as an index of relative abundance in many fisheries worldwide, due to commercial fleet catches can be considered as a sample of the population[30]. Variations of this index are mainly associated to changes in the characteristics and composition of the fleet as well as of the environmental factors[31,32]. Some reviews about the type of standardization necessary for the correct calculation of CPUE exist in relation to the peculiarities of each fishery[33,34]. The identification of a strong and significant linear relationship between the number of individuals harvested and count density is generally considered sufficient to justify the use of catching records as a proxy for population changes. In some cases, even when this relationship is not clear, the harvesting time series may still reflect the underlying density dependent on structure and dynamics[35]. Furthermore, an improper use of CPUE data can result in bias in the assessment of stock status[36]. Therefore, it is critically important to standardize CPUE, so that CPUE is comparable among years and may be used as a reliable index of abundance. Standardization can be a simple process involving the correction of fishing power of the whole fleet in comparison with a standard vessel[37]. Thus, to evaluate the reliability of abundance indices calculated through standardization of commercial catch and effort data is required fishery-independent estimates of stock abundance from the same fishery[29]. The most recent methods for standardizing catch and effort data compare CPUE data from multiple sources by accounting for several factor effects through the use of mathematical models among them, generalized linear models, generalized additive models, and generalized linear mixed models. For a better understanding of these methods, a review is recommended[33,34,38]. Sometimes there may be a potential effect of gear upon CPUE, which can be removed by taking the residuals of a linear model explaining each statistic as a function of a factorial effect gear[39]. Thus, in this proposal, as a first approximation, correct CPUE or landings per unit effort long time series are needed to build a previous and conventional stock dynamic model, by incorporating system-intrinsic processes and exogenous influences as an autoregressive model relating the current density of a population to past densities as follow:

Let $CPUE_t$ be the abundance (or a density proxy) of a stock at time t; where CPUE stands for the parameter N in the original algebraic equation. In other words, the abundance N is changed by CPUE values per year. Furthermore let εt be an exogenous input composed of density-independent "random shocks"[40,41]; then:

$$CPUE_t=CPUE_{t-1}F'(CPUE_{t-1},CPUE_{t-2}, ...,CPUE_{t-d},\varepsilon_t) \quad (1)$$

Where d denotes the number of lags included as the order of the autoregressive process. Correct estimation of d is critical for successful forecasting, because both underestimating and overestimating this parameter will lead to decreased accuracy of forecasts. Moreover, the estimated value of d to generate hypotheses about the proximal (biological) causes driving population fluctuations can be used[26,41]. A minimum of 11 years (d) must be considered into the time series data following Harrell´s criterion about degrees of freedom for setting a model[42], as the maximum "time delay" in density dependent regulation[40,43]. Also, Equation1 can be expressed as a R-function in terms of the realized per capita stock growth rates that represent the processes of individual survival and reproduction, defining $R_t=log(CPUE_t)-log(CPUE_{t-1})$[26], where:

$$R_t=f(CPUE_{t-1}, CPUE_{t-2},\ldots, CPUE_{t-d}, \varepsilon_t) \quad (2)$$

Note the change in algebraic expressions from the original equations[26]. Also, the information about climatic effects, as exogenous factors upon the fishes' populations, can be included indirectly due to landings data are reported per year[25]. However, the most interesting hypothesis would be the possibility of diagnosing human predation upon CPUE time series.

3. CPUE time series analysis

The most commonly used diagnostics in conventional time series analysis have been the autocorrelation and partial autocorrelation functions (ACF and PACF respectively[44]. Currently, some researches apply autocorrelation analysis of CPUEs[14]. On the one hand, ACF can not detect the dimension of the feedback processes operating on the population, or the number of lags that should be included in a population model. This problem is analogous to that of deciding the number of terms to be included in a multiple regression equation. On the other hand, PACF is supported by an autoregressive model that is not well suited to biological systems due to changes in biological populations which are brought about by changes in individual organisms. In order to propose a feasible solution, partial rate correlation function (PRCF) – in which the present communication is based on – has been proposed, showing how the addition of a term to the model increases the coefficient of multiple determinations. Both, PACF and PRCF differ in their null models and two analyses have been tested, concluding PRCF is a more useful diagnostic tool for evaluating the density dependent structure of ecological time series, being relatively good for long time series[45]. If Eq. 1 is taken in consideration, where the function F′(...) represents the obtained per–capita rate of population change, where the logarithmic per–capita rate of change–$R_t=ln(CPUE_t/CPUE_{t-1})$ – should be used as the dependent variable in the stepwise regression. So that log–transforming the replacement rate linearizes the growth process and makes the statistical estimation procedure better behaved, having the model in Eq. 3:

$$R_t=L_t-L_{t-1}=a_0+a_1L_{t-1}+a_2L_{t-2}+\ldots+a_dL_{t-d}+\varepsilon_t \quad (3)$$

Where $Lt\equiv ln\ CPUE_t$, d is the order of autoregressive process, ε_t again represents the exogenous component and ai as the constants of regression. In this model the differenced series ($R_t = L_t-L_{t-1}$) are regressed against lagged population densities (L_{t-1}, L_{t-2}, ...) as shown in Eq.4. This resulting model is based on the model transition explained in detail in a recent research[24]. Significance can be roughly assessed by Bartlett′s criterion $2\sqrt{n}$, with n standing for the length of the time series[45].

$$PRCF=\frac{\Sigma(L(t)-\bar{L})\,[R(t)-\bar{R}]}{\sqrt{\Sigma(L(t)-\bar{L})^2\,\Sigma\,[R(t)-\bar{R}]^2}} \quad (4)$$

It is important to notice that when PRCF has a negative correlation coefficient at lag 1 indicates the presence of direct density dependence, as a negative feedback of first order resulting from intraspecific interactions, such as competition for food or space, scramble competition, *etc*. While second order occurs, *i.e.* a negative correlation coefficient at lag 2, often result from interactions between species, particularly between consumers and their resources[26,40,41,45]. As a matter of fact, in fisheries, the consumers are human beings and the resources are the fishes, despite the natural predation. So this approximation can provide us information about the possible fluctuations caused by exogenous or endogenous processes in spite of the extraction of fishes.

4. Data interpretation and current approaches

Nowadays, there are several researches based on analysis of CPUE′s, both oceanic[14–19,46–50] and freshwater[51], including marine protected areas[52–54], in which the fish population trends are resulted of spatio–temporal studies of abundance time series. However, there are few researches on fisheries that have provided information through the PRFC analysis on commercial landings time series using CPUE as an abundance index. On the one hand, using these two techniques of analysis, some researchers have tended to obtain the information about the noisy atmospheric variables that may act as exogenous factors included in the population dynamics processes, as well the possible effect of human predation on artisanal fisheries[24,25]. On the other, the data interpretation, based on extraction gear of the fishes, analysis of both, exogenous and endogenous factors using CPUE and PRCF, as well as Bayesian Information Criterion resulted on the value of the artisanal gear and its sustainable development taking on account the endogenous processes in population dynamic of the exploited stock of *Thyrsites atun* (*T. atun*) in Chile[25], as we can see in Figure 1, the obtained results show a first dynamic order where endogenous process might be implied on the population dynamic, having a negative correlation coefficient at lag 1. Moreover, if CPUE time series of the West Chatham Rise Stock from New Zealand[55] are analyzed (Figure 1), it is observed, a priori, that *Merluccius australis* (*M. australis*) population dynamic follows a first order dynamic (Figure 2), in spite of its diminishing abundance or its diminishing captures[55,56] – these data are available in open access. This result might indicate that population dynamics might counteract the diminishing abundance of fishing resources as a consequence of human activity, keeping first order dynamics. In other words, PRCF analysis on *M. australis*

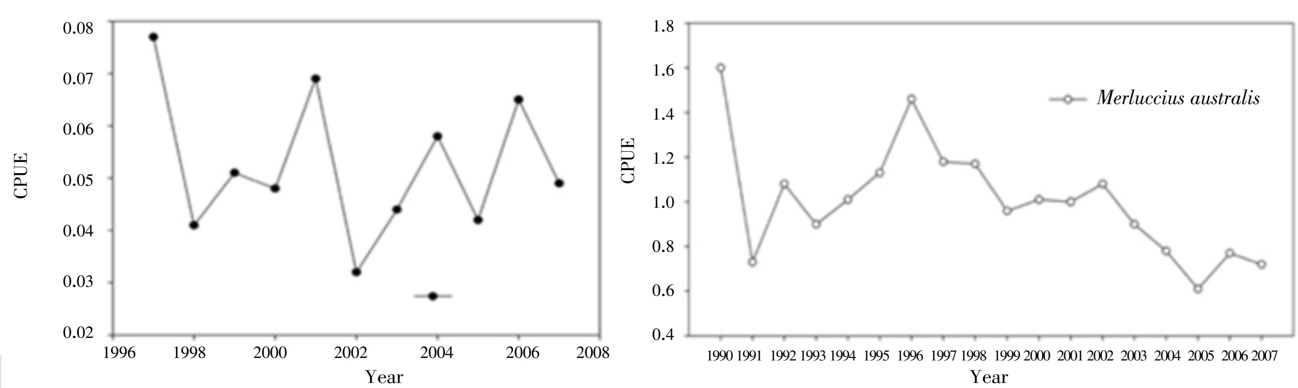

Figure 1. CPUE time series of *Thyrsites atun* (extracted from Vázquez–Prada, 2013) and *Merluccius australis* (data from Devine 2013, New Zealand Fisheries Assessment Report).

has a negative correlation coefficient at lag 1 indicating possible intraspecific interactions regulating its dynamic. In contrast, both stocks showed a first order dynamic despite of the different trends in its CPUE time series (Figure 1). The knowledge of the kind of factors that might be implied on stocks dynamics using PRCF may constitute itself as a new approach for fishery management.

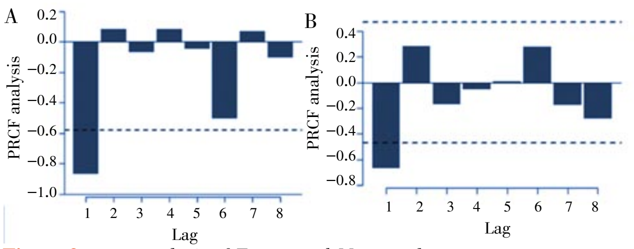

Figure 2. PRCF analysis of *T. atun* and *M. australis*.

A: *T. atun* PRCF analysis (extracted from Vázquez-Prada, 2013). B: *M. australis* PRCF analysis (data from Devine 2013, New Zealand Fisheries Assessment Report).

5. Discussion

It is a well-known fact that there are many criticisms to the use of CPUE as an index of abundance. Moreover, sometimes, the validity of the study data from commercial fishing is questioned and as well as one of the biggest problems when estimating abundance from landings is the presence of different cohorts[30]. At the same time, before applying the theory of population dynamics in a particular situation, it is necessary to determine how the fish population and the fishery can be treated as a unit system[2]. However, "stock unit" is an operational issue and if in an area species are caught in the same fishing grounds with the same gear, then at least in the early stages of analysis, when the data are sparse, it may be permissible to treat them as a single stock unit. Despite, often, how large the existing fisheries are, and where they operate is not known accurately, because of the fact of widespread cheating and budget constraints for the national and international agencies in charge of monitoring fisheries[9,30]. If CPUE time series data are used, it is necessary to have in account that time series of commercial catch contain, as is generally the case for most ecological time series, noisy and mixed information, whose respective effects of climate variability, environmental forcing, population dynamics and exploitation, and disentangling the relative effects of the many factors affecting populations dynamics as well as the geographical scale and type of gear, for instance the province scale, where the patterns of variation of the CPUE time series are more related to the type of fishing gear than to the species. What is to say, the CPUE of different species fished with the same gear displays more common fluctuations than the CPUE of a given species fished with different gears, and thus, at the province scale the gears represent the most important effect[39]. In the last decade, researchers have used CPUE time series to explain trends in patterns every year in relationship with climatic variables[22,39,47] and some studies remark the needing of a correct CPUE standardization[57,58], so what is new? Theoretically, fisheries scientists, using PRCF analysis, could be able to find the underlying order of population dynamics and relate it with endogenous or exogenous factors involved in population fluctuations; in addition, analyzing the patterns of variations of different fish species, in contrasting environments and subject to a variety of fishing pressures, expecting to cast light on the relative effects of these factors and/or the way they interact. So, if PRCF analysis shows a first-order dynamics, *i.e.* an endogenous dynamics of negative feedback underlying the fluctuation of a single stock, it can lead to think of the sustainable management of the fishery responsible of the resource analyzed, because stock fluctuations should be regulated by endogenous processes. At the same time, if there is a second order dynamic, where fluctuations would be derived from the action of external factors, scientists can hypothesize that the dynamics might be regulated by an extraction correlated with the abundance of fishes, as well as the possible influence of the climatic variables. Furthermore, information about the dynamic order can be explored, even in cases of overfishing. However, the primary limitation of PRCF is that it is based on a linear model while real population dynamics can be highly nonlinear[26,40], for this reason, its proper role in ecological time series analysis is for diagnosis rather than modeling. It is particularly important that the time series are stationary and that the likelihood of exogenous causal factors have been ruled out. Note time series analysis is not an end in itself but rather a starting point for detecting the causes of population fluctuations[45], including this analysis as a new approach into the fishery management context. This communication is a call to give effect to the proposal of employing these two techniques, combining CPUE time series, standardizing fleet catches and subsequent analysis PRCF study to determine whether stocks fluctuations are given by processes endogenous such as contest or scramble competition[26], or if instead there are fluctuations due to exogenous factors (density-independent) such as ambient noise produced by climate changes or by human predation, so to take into consideration and evaluate the human activity within the biological systems is crucial, as there are no marine areas unaffected by human influence[3].

Conflict of interest statement

We declare that we have no conflict of interest.

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reviewer.

Comments

Background

Ecology-based approaches are important and widely used in fishery scientific researches. Therefore, there is need of new statistical techniques to assess the state of exploited fish stocks and provide the advice to fishery managers.

Research frontiers

This research integrated of CPUE time series into a PRCF analysis to get information about the population dynamic order of each stock exploited.

Related reports

PRCF is widely used in ecological fields, but has not been much used in fisheries and aquatic sciences. CPUE has been used in many fisheries researches worldwide like an abundance index.

Innovations and breakthroughs

For statistical analysis, the author explored a new method combined with CPUE and PRCF.

Applications

This method could determine whether fish stocks fluctuations are given by processes endogenous or exogenous factors such as ambient noise produced by climate changes or by human predation.

Peer review

This is a good writing paper. The study explored a new method combined with CPUE and PRCF to assess the state of exploited fish stocks and discussed whether the potential impact of population dynamics of fish stocks relate with endogenous or exogenous factors.

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