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Expected economic value of the information provided by fishery research surveys

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ABSTRACT

Information gathering can reduce critical uncertainties and, consequently, lead to better decisions on conservation and exploitation of fisheries. Such decisions might improve the fishing opportunities or lower their variability. However, information gathering comes at a cost. The concept of the expected value of information is based on the idea that decisions will be more accurate if the decision maker has more information. The objective of this work is to use this concept to measure and understand the economic value of fishery research surveys using the mathematical theory of the expected value of information. The Bay of Biscay anchovy fishery is used as an example, given the importance of the surveys in the assessment and management in this fishery. The paper provides a measure of the value of information obtained by research surveys. It also analyses the properties of these values, considering the methodology used, and examines the circumstances under which such calculations are adequate. The sources of subjectivity inherent to this methodology and to the general concept of information signals in the fishery assessment and management are explored.

1. Introduction

Uncertainty is unavoidable in the stock assessment, advice and management of fish stocks. Even though this issue is acknowledged in management strategy evaluation (Punt, 2015), information gathering can help to reduce critical uncertainties and, consequently, improve management decisions. Reducing uncertainty should help the managers to make more accurate management decisions or at least form a clearer picture of expected outcomes. In the stock advisory process, it can improve fishing opportunities without increasing risk or, at the very least, reduce the variability of the future fishing opportunities. Information gathering can include fundamental research, assessment, monitoring and analytical processing of gathered data. However, such information gain comes at a cost, and it is essential to measure the economic value of the information.

The concept of the expected value of information (EVI) is pivotal in the economics of information (Stigler, 1961; Howard, 1966). The idea is simple: the accuracy of the decisions will improve if the decision maker (DM) receives more information.

The EVI has been used in many scientific areas, such as health decision-making (Doug and Jeremy, 2008; Fenwick et al., 2000; Rachael, 2007; Welton et al., 2008) and agriculture (Pannell, 1994; Wuyang et al., 2005), among others. However, it has not often been used in the scientific evaluation of fisheries. Mäntyniemi et al. (2009) discussed the value of hypothetically perfect knowledge of the type of stock-recruitment function for the North Sea herring, Punt and Smith (1999) analysed the value of collecting new data to improve the management of one stock, and Peterman (1990) examined the value of fishery research. This last study showed that a statistical power analysis can help in interpret available results and improve the design of future experiments. There are only a few scientific studies of the economic value of fishery research surveys. Dennis et al. (2015) assessed the relative value of different combinations of fishery survey methods, using a modelling approach, while Zimmermann and Enberg (2016) present an analysis of the required frequency of surveys and assessments. These authors found that the frequency of assessments can be reduced and still provide similar stock estimates, decreasing the overall costs in the case of two Northeast Atlantic stocks, blue whiting and Norwegian spring-spawning herring,

Here, a different approach was taken. The value of the research survey itself was assessed, but not the frequency of research surveys. Furthermore, in contrast to Dennis et al. (2015), the subjectivity of the management DM was considered. The objective was to provide a methodology to measure and understand the economic

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value of the fishery research surveys and information gathering in general, to improve the management decisions of a DM.

The mathematical theory of the EVI was applied here to the Bay of Biscay anchovy fishery where independent research surveys play an important role in the stock assessment process and in the management advice provided by the associated scientific body.

2. Methods

2.1. Study system

The anchovy fishery in the Bay of Biscay has often been described in the scientific literature (Uriarte et al., 1996; Lazkano et al., 2013; Andrés and Prellezo, 2012; Del Valle et al., 2001, 2003, 2008). Anchovy is evaluated, as are many other species, on a single stock basis, by the Working Group on Southern Horse Mackerel, Anchovy, and Sardine (ICES, 2016) of the International Council of the Exploration of the Sea (ICES). The data on catches, overall and by member state, were obtained from this source.

Two member states are involved in this fishery: France and Spain. The management of this fishery involves a system of vessel entry licenses and a system of Total Allowable Catches (TACs) and quotas. The vessel entry licensing system is managed by the individual member states while the European Union (EU) decides on the TAC. Hence, three DMs are involved in the management of this stock. The TAC advice during 2015 and 2016 was produced using a harvest control rule (HCR) based on that the spawning stock biomass (SSB) does not fall below a lower limit reference point for SSB with a probability of 95%. According to this HCR, the TAC advised will be zero if the predicted SSB is below 24,000 t; 33,000 t if it is above 89,000 t and $-2,600 + 0.4\hat{SSB}$ (where $\hat{SSB}$ is the predicted value of the SSB) if it falls between these two limits (STECF, 2014).

Neither of the fleets involved in this fishery is strictly economically dependent on anchovy. The vessels from the member states also fish other species, such as mackerel, tunas and hake. According to the bilateral Arcachon agreement, the Spanish fishery is active in the spring (April to June), and French vessels are at sea for the remaining months of the year. Approximately 85% of the catches occurs in the south-eastern corner of the Bay of Biscay, and almost 95% of the French landings are sold on the Basque markets (Pita et al., 2014). Therefore, the prices used in the analysis were obtained for the landings in these markets (source www.eustat.es). They have been adjusted to 2015 level using the Spanish inflation rate (see Supplementary data for time series of deflated revenue).

Fig. 1 presents the evolution of the real revenue (inflated to 2015) for the two member states from 2003 to 2015. Three different periods can be distinguished. From 2003 to 2006, the trend of the real revenue was negative. From 2007 to 2009, the fishery was closed due to successive recruitment failures that ended in the collapse of the stock. In 2010, the fishery was re-opened and, from that point, the revenue has shown a positive trend.

The assessment of the Bay of Biscay anchovy has been conducted using a two-stage, biomass-based state-space model with stochastic recruitment and deterministic dynamics. The model is fitted in a Bayesian context using a Markov chain Monte Carlo technique (see Ibaibarriaga et al. (2011) for further details). The required input data include commercial catches, fish numbers by age and the indices of biomass and recruitment produced by research independent of the commercial fishery. In 2016, three such independent sources of information were used in the assessment for the Bay of Biscay anchovy:

- BIOMAN daily egg production survey conducted in the spring (BIOMAN hereafter). The data for this index are available from 1987 to 2015 (26 observations, indices for some years missing).
- The PELGAS spring acoustic survey (PELGAS hereafter). The time series for this index is available from 1989 to 2015 (22 observations, indices for some years missing).
- The JUVENA autumn acoustic survey of juveniles (JUVENA hereafter). The data for this index are available from 2003 to 2015 (13 observations, no missing observations).

Each of these three research surveys produces one index of biomass (ICES, 2016) for the Bay of Biscay anchovy. The study analyses the economic value of these surveys for the period starting in 1987 and ending in 2015.

2.2. Analysis

It was assumed that the goal of the DM is to evaluate the economic value of different signals of information. To achieve this goal, the expected value of perfect information (EVPI) was used (Raiffa and Schlaifer, 1961). It can be mathematically formulated as:

$$EVPI = \sum_{x} \left(E_x \left[max_a \left[U\left(a, x\right) \right] \right] - max_a E_x \left[U\left(a, x\right) \right] \right) \quad (1)$$

where a is the management decision taken by the DM and x is a hypothesis for the system. In the studied system, a is the TAC to be set by the DM and x is the SSB expectation formed by the DM for this stock, given the available information. $U(a,x)$ is the utility associated with decision a under the system x. In this case, the utility is the value ascribed by the DM to the outcome, and is the measure of the management decision performance. Two possible management measures were considered: the real revenue and the landings obtained by all the fishing fleets involved in the fishery. $E[max_a U(a,x)]$ is the expected value when all the uncertainties are resolved by the DM, who then takes the best management decision, while $max_a E_x[U(a,x)]$ represents the expected value when the DM does not have or does not use any information to make the (best) management decision. The difference shown in Eq. (1) is, therefore, the expected utility gain from acquiring the perfect information or the opportunity cost of not using (acquiring) it.

Information signals do not necessarily provide the perfect information and do not necessarily reduce the uncertainty to zero. In such cases, instead of calculating the value of perfect information, it is worth calculating the expected value of imperfect (or sample) information (EVII) (Yokota and Thompson, 2004; Raiffa and Schlaifer, 1961). Mathematically:

$$EVII = \sum_{x} \left(E_s \left[max_a E_{x\setminus s} \left[U\left(a, x\right) \right] \right] - max_a E_x \left[U\left(a, x\right) \right] \right) \quad (2)$$

where $E_s[max_a E_{x\setminus s} U(a,x)]$ is the expected benefit derived from using the (imperfect) information provided by the signal (s) and then making the best management decision. Eqs. (1) and (2) are related, in the sense that EVII = EVPI when the signal is providing perfect information.

EVPI is easier to calculate than EVII because the likelihood assessments and Bayesian calculations are trivial. In this particular example, the algorithm used to solve Eq. (1) was based on calculating the opportunity cost of not using or not acquiring information. The algorithm can be summarised in six steps (see Supplementary data for the R code):

1. Select the management measure (revenues or landings) and calculate its mean and standard deviation.
2. The mean value of the management measure was considered the maximum expectation of the DM for any possible hypothesis explaining how the system works (x), given the management