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Perceived impact of offshore aquaculture area on small-scale fisheries: A fuzzy logic model approach

Jorge Ramos[a,*], Pedro G. Lino[a], Miguel Caetano[b,c], Fábio Pereira[a], Miguel Gaspar[a,d], Miguel Neves dos Santos[a]

[a] IPMA, Av. 5 Outubro s/n, 8700-305 Olhão, Portugal
[b] IPMA, Av. de Brasília, 6, 1449-006 Lisbon, Portugal
[c] CIIMAR, Rua dos Bragas, 289, 4050-123 Porto, Portugal
[d] CCMAR, University of Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

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ABSTRACT

Recently an action plan has been put in place off southeastern Portugal, consisting in an offshore aquaculture area off the Armona sandy barrier island, Armona Pilot Production Aquaculture Area (APPAA). The infrastructure was created after the initiative of the Portuguese Government aiming to stimulate local employment opportunities related to seafood production. The APPAA aims to improve resilience of finfish and shellfish production for the future. However, the delimited infrastructure is located nearby some fishery-dependent communities. Therefore, such proximity may cause friction with some fishermen due to the limitations post APPAA development (e.g. may feel their jobs are threatened). In this study, we queried the reasoning rules elicited by local fishing communities and their perceived impact of the APPAA implementation. In that scope, a fuzzy logic expert system approach was used to investigate the interaction between three input variables (namely, 'availability of fishable area', 'navigational disturbance', and 'catch variation') and the output variable (i.e., overall 'fishing community satisfaction'). The results from the fuzzy logic expert system showed that 'catch variation' was the input that most affected 'fishing community satisfaction' and seemed to be the one that suffered most changes. The results also show that, for the analyzed years, where the catch was higher, the degree of satisfaction tended to follow the trend, independently of the fishing community. The other two input variables were more conditioned by governmental arrangement ('availability of fishable area') and by small-scale fishermen reaction ('navigational disturbance'). The fuzzy logic expert system proved to be a valuable tool, facilitating the analysis of governance arrangements, particularly those dealing with the interaction between the fisheries–offshore aquaculture system as a whole.

1. Introduction

Since the mid-1970s, aquaculture has been growing almost exponentially (Bostock et al., 2010). However, it was only during the 1990s, following decreases in wild catches (Pauly et al., 1998), scarcity of suitable coastal areas for aquaculture (Klinger and Naylor, 2012) and concern over impact to the environment (Shainee et al., 2013) that many coastal countries started to expand aquaculture from near to offshore areas located on continental shelves (e.g. Schatzberg, 2002; Buck et al., 2004; Longdill et al., 2008). Additional support for this relocation is because offshore areas within the continental shelf are among the most productive areas in the world (Chen, 1996; Macpherson and Gordoa, 1996; Farías et al., 2004). Therefore, it is argued that offshore aquaculture can be the solution for the growing demand for seafood (Wheeler, 2013).

In terms of costs, offshore aquaculture presents some advantages over inshore systems, particularly due to the higher flush effect in open water (Troell et al., 2009) and less local pollution and associated benthic stress (Naylor and Burke, 2005). However, offshore aquaculture also presents additional risks due to the high energy environment and a decrease in staff safety (Knapp, 2008; Sturrock et al., 2008). Few conflicts have been found between offshore aquaculture and activities related to tourism, recreation or coastal esthetics (Stickney, 1997; Teitelbaum, 2011). Nevertheless, some drawbacks are recognized related to biological–ecological or social–economic issues (e.g. Suryanata and Umemoto, 2005).

* Corresponding author. Tel.: +351 289 700 500.
E-mail addresses: jramos@ipma.pt, jormos@gmail.com (J. Ramos), plino@ipma.pt (P.G. Lino), mcaetano@ipma.pt (M. Caetano), fpereira@ipma.pt (F. Pereira), mbgaspar@ipma.pt (M. Gaspar), mnsantos@ipma.pt (M.N. dos Santos).

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In the case of the former, sedimentation of uneaten food pellets and feces (Ervik et al., 1997), transmission of parasites, viruses and bacterial diseases (Goldburg and Naylor, 2005) and escapees (Naylor et al., 2005) are amongst the most commonly referenced problems. From a social-economical view several situations may occur, namely clashes with commercial fishing (Sivas and Caldwell, 2008) where ocean leasing may result in the occupation of former fishing areas (Barnaby and Adams, 2002), interference with navigation (Lovatelli et al., 2013), affection of catch composition or even competition with wild catch fisheries (Valderrama and Anderson, 2008).

There is high dependence on fish imports for countries within the Organization for Economic Co-operation and Development (OECD) (Schmidt, 2003). To deal with this the EU is promoting projects related to sustainable fish production (Penas, 2007). Portugal is the largest seafood consumer *per capita* in Europe (over 60 kg/year), and approximately 2/3 of the seafood consumed are imported (Bjørndal et al., 2015). As a consequence Portugal has created a policy agenda devoted to reducing the seafood trade deficit (Carneiro, 2007; Stelzenmüller et al., 2013). As a result, various offshore aquaculture projects as well as small-scale fisheries have been evaluated (Soma et al., 2014). For instance, Shester and Micheli (2011) noted that small-scale fisheries are very important in social, economic and ecological terms because they employ 9 out of 10 fishermen, provide over half the world's wild seafood, and are considered more sustainable than industrial fisheries. Small-scale fisheries also have few conflicts with industrial fisheries because they operate at different depths and consequently occupy different zones. In contrast small-scale fisheries may be in conflict with offshore aquaculture developments where these are developed in former fishing areas (Charles, 2011).

The barrier islands that delimit the Ria Formosa lagoon have been inhabited since the 19th century (Bernardo et al., 2002). The islands were formed by the deposition of sand and salt intrusions make the soil unsuitable for agriculture (Bouvet and Le Toan, 2011). Therefore the local communities have long depended on local fishing grounds accessible by daily fishing trips. Therefore the establishment of offshore aquaculture production areas that competes with traditional fishing activities are a potential source of conflict that need to be accounted for in coastal areas management.

In this case study, the effect of offshore aquaculture on four fishing communities was investigated using a fuzzy logic approach. The (dis)satisfaction of small-scale fishermen was analyzed based on elicited issues and attributes and combined in different ways (using heuristic rules).

In Portugal there is a lack of information on small-scale fisheries due to their complexity and the dynamic nature of this sector (Guyader et al., 2013). There is also an intrinsic difficulty in dealing with several factors, such as: number of fishing days, time spent fishing and cruising, target species (Gaspar and Pereira, 2012). The relative small size of most fishing vessels limits the possibility of carrying electronic equipment for positioning and creates uncertainties when managing these fisheries. Consequently ensuring adequate governance of the coastal area is a difficult task.

The development of a marine spatial plan (POEM) was commenced in 2008. Stakeholders, competing interests and ways to promote coexistence were identified (Calado et al., 2010). The different activities and stakeholders' interests including interaction between small-scale fisheries and offshore aquaculture have been described by Ramos et al. (2015).

2. Fuzzy logic background

2.1. State-of-the-art

Since Zadeh (1965), fuzzy logic has been used in several fields, e.g. engineering (e.g. Mendel, 1995; Ross, 2009), economics (e.g. Low and Poon, 2008; Alaneme and Igboanugo, 2012; Díaz and Morillas, 2012), environment (McKone and Deshpande, 2005; Kuo et al., 2009), social (Hassan et al., 2010; Zlateva et al., 2011) and political policy (Gökşen et al., 2012; Pal and Tyagi, 2014). A particular emphasis has been given to fuzzy logic studies on marine issues, namely: (i) coastal and marine management (Ergin et al., 2004; Blauw et al., 2010; Teh and Teh, 2011), (ii) fisheries conservation (Cheung et al., 2005; Morato et al., 2006; Ainsworth et al., 2008), (iii) fisheries decision making (Paterson et al., 2007; Jarre et al., 2008), (iv) social issues related to fisheries (Grant and Berkes, 2007; Ommer et al., 2012), and (v) aquaculture control systems (Lee et al., 2000; Soto-Zarazúa et al., 2011).

2.2. Theoretical approach

Fuzzy logic is used in cases with a high degree of uncertainty (Guillaume and Charnomordic, 2011), and is a valuable method for dealing with problems where exact values are not available. It is an extension of Boolean logic where values are either 0 (FALSE) or 1 (TRUE), but allows intermediate values e.g. 0.5 (MAYBE) (Berchtold et al., 2008). Fuzzy set theory allows an object to have partial membership in more than one set. This is possible through the membership function. According to Phillis and Andriantiatsaholiniaina (2001), fuzzy logic uses linguistic variables defined by four components: (a) the name of the variable (e.g. catch); (b) its linguistic terms/values (e.g. 'low' and 'high'); (c) the membership functions of the linguistic values; and (d) the domain over which the variable takes its quantitative values. Depending on the approach used, the rational for the fuzzy logic includes three processes (Wang and Mendel, 1992; Wang, 1999): (i) fuzzyfication, (ii) inference, and (iii) defuzzyfication.

2.2.1. Fuzzyfication

Consider x an element of a given set X, a fuzzy set ($\tilde{a}$) is represented by the degree of membership [$\mu_{\tilde{a}}(x)$], which quantifies the grade of belongingness of the element x to the fuzzy set ($\tilde{a}$). The membership function which represents a fuzzy set $\tilde{a}$ is represented by μ_a. The degree of membership varies between 0 (x is not a member of the fuzzy set) and 1 (the fuzzified variable x is an absolute member of the fuzzy set). The given membership functions should represent linguistic terms with adequate semantic meanings (e.g. for three terms: low, average, high). Upper and lower threshold shape the membership range. Fuzzyfication is the translation of each crisp value into a term and grade of the membership function. The combination of the term and the grade is denominated as fuzzy set. There are different methods to proceed with fuzzyfication, for example the triangular method is widely used (Chen and Susanto, 2003). According to Tseng and Chiu (2013), a triangular fuzzy number ($\tilde{a}$) is defined by a triplet (l, m, u) and its membership function is defined by:

$$\mu_{\tilde{a}}(x) = \begin{vmatrix} (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-l) & m \le x \le u \\ 0 & \text{otherwise} \end{vmatrix} \quad (1)$$

2.2.2. Inference

This process is based on human empirical experience and in data collected in the field or though experiments. Using logical operators (e.g. AND, OR, NOT) and heuristic clauses (IF-THEN rules) the membership functions from the fuzzification process are combined. The IF conditions/antecedents represent the input variables, while the THEN actions/consequences represent the output variables. Basically, there are two ways to present fuzzy rules: (i) the