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Identification of potential aquaculture sites in solar saltscapes via the Analytic Hierarchy Process

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ABSTRACT

The European Commission has identified competition for space as one of the main factors contributing to the stagnation of EU aquaculture production and has recommended coordinated spatial planning, as a mean to identify sites with favorable operational characteristics for aquaculture and lower potential for conflict with other activities. In coastal areas of the Mediterranean, pond aquaculture has emerged as an alternative to salt production in abandoned artisanal Salinas, compromising the delivery of Ecosystem Services in wetland areas. To establish a methodology to estimate the physical carrying capacity for coastal pond aquaculture, and the contribution of the ecosystem to the value of provisioning services from aquaculture, while minimizing the competition for space with solar salt production, we applied a multicriteria-decision making tool (AHP method) to identify priority areas for extensive and semi-intensive aquaculture development in solar saltscapes, taking into account physical factors of ecological and social nature. The study presents spatial allocation scenarios for aquaculture development in the saltscapes of the Figueira da Foz, in the Atlantic coastal zone of Portugal. The physical carrying capacity for the two scenarios presented indicates a potential increase of the area occupied by aquaculture farms in ponds previously occupied by inactive farms and flooded/land filled salterns, whose sites tend to minimize conflict with salt production through avoiding the same water input location and being adjacent to active farms. In conclusion, the approach applied has proven to be successful to manage space competition between aquaculture and salt production, contributing to a sustainable increase of the value of the provisioning of ecosystem services from aquaculture. In future studies, estimation of the social carrying capacity should be combined with the approach followed in this study to improve the definition of the acceptable social limits for aquaculture development in saltscapes.

1. Introduction

1.1. Sustainable aquaculture

The European Commission has identified aquaculture as one of the pillars of the EU's Blue Growth Strategy (EC, 2012) and proposed non-binding strategic guidelines towards the economic, social and environmental sustainable development of aquaculture (EC, 2013). One of the main recommendations is the increase of production through coordinated spatial planning (EC, 2013), as a mean to identify sites with favorable operational characteristics for aquaculture and lower potential for conflict with other activities (Henriques et al., 2017, Gentry et al., 2016). Aquaculture competes for ecological, physical, economic and social resources with other sectors such as fisheries, salt production and tourism (Benessaiah and Sengupta, 2014; Dalton et al., 2017; Gimpel et al., 2018; Paéz-Osuna, 2001).

In coastal areas, competition for space has been identified as one of the main factors contributing to the stagnation of EU aquaculture production (Hofherr et al., 2012; Hofherr et al., 2015). For inland aquaculture, such hurdle may be overcome implementing spatial plans that "take into account the environmental services provided by extensive pond-based aquaculture" in a multi-use context (EC, 2013). Among the possible approaches to this problem is the recovery of wetlands through dual purpose wetlands/aquaculture ponds (Walton et al., 2015; Paéz-Osuna, 2001) and the recovery of abandoned saltwork ponds (Buestel, 2005; Santulli and Modica, 2009). Both strategies incorporate conservation and extensive aquaculture activities in compliance with the ecosystem approach to aquaculture (EAA) promoted by UNEP and FAO (FAO, 2010). The EAA "is a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems" (FAO, 2010).

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An EEA strategy, ensuring environmental, economic and social sustainability, can only be put in practice if aquaculture facilities adjust their production to the carrying capacity of the local environment and social context (Ross et al., 2013). “Carrying capacity for any sector can be defined as the level of resource use that can be sustained over the long term by the natural regenerative power of the environment” (Ross et al., 2013). The concept helps defining the upper limits of aquaculture production given the environmental limits and social acceptability.

Although the general views of carrying capacity for aquaculture are based solely on production, they have been developed further into a more comprehensive four-category approach based on physical, production, ecological and social carrying capacity (FAO, 2010; Inglis et al., 2000; McKindsey et al., 2006). The physical carrying capacity has been defined as the total area that can be accommodated for aquaculture in the available physical space. It determines the development potential in any location, taking into account the physical factors of the environment, such as salinity, temperature and infrastructures. From a decision-making point of view, the physical carrying capacity is the first step towards the identification of suitable areas for sustainable aquaculture development, as it is recognized as a broader site selection criterion. The production carrying capacity estimates the maximum aquaculture production at restricted areas, such as farm or delimited regions within a water basin, dependent upon the technology, production system and financial investment. The ecological carrying capacity estimates the magnitude of aquaculture production (stocking or farm density) that can be supported without leading to significant changes to the environment. The social carrying capacity calculates the level (intensity, productive system, etc.) of farm development that can be developed without adverse social impacts.

1.2. Multicriteria Decision-Making for aquaculture

The success of an aquaculture project depends largely on the proper selection of a site to develop a fish farm or hatchery. This involves seeking for optimal solutions to multiple alternatives, frequently managing conflicting issues between stakeholders with conflicting objectives. A valuable tool to select the “optimal solutions” is the Multicriteria Decision-Making (MCDM) framework (Communities and Local Government, 2009). MCDM embraces a collection of approaches that support complex decision-making situations helping stakeholders to explore decisions that matter (Mendoza and Martins, 2006).

For the aim of aquaculture development, MCDM methods have been seen variably as (i) a decision-support system that integrates biological, ecological and socio-economic values (Mamat et al., 2014; Micael et al., 2015; Wijenayake et al. 2016); (ii) an impact and risk assessment tool (Falconer et al., 2013; Rekha et al., 2015; Seekao and Pharino, 2016); and (iii) an approach to elicit stakeholders’ preferences on key issues for the development of aquaculture (Lembo et al., 2018). MCDM methods have frequently been used in spatial explicit models, supporting site suitability assessments (Hossain et al., 2009; Mamat et al., 2014; Micael et al., 2015).

One of the most widely used MCDM methods is the Analytic Hierarchy Process (AHP) (Saaty, 1980; Altuzarra et al., 2007). AHP considers qualitative and quantitative information and combines them by decomposing ill structured problems into systematic hierarchies by deriving ratio scale weights and priorities through pairwise criteria comparison (Chen et al., 2008; Saaty and Vargas, 1991). Advantages of this method arise from (i) the binary comparisons between just two objectives, which reduce the cognitive burden (Hall et al., 2004); (ii) the calculated numerical weights, which introduce some objective judgement to subjective processes (Mau-Crimmins et al., 2005); and (iii) the flexibility of the method, which allows decision-makers to structure the decision problem according to the specific characteristics of the area (Hossain et al., 2009). The method has nonetheless been criticized mainly due to the problem of rank reversal, i.e., the changes that may occur in rankings when adding one new alternative (Robins, 2004). Despite its pitfalls the method is suitable for individual and group decision making (Yavuz and Baycan, 2013; Sutadian et al., 2017; Morgan, 2017) and has been applied in many research fields, including nature, economy and society (Saaty, 1996; Latinopoulos et al., 2012; Chen et al., 2014; Zhang et al., 2014; Li et al., 2016; Ying et al., 2007). In particular, the AHP method has been applied in aquaculture site selection studies (Falconer et al., 2016), frequently coupled with geographic information systems (Hossain et al., 2009; Radiarta et al., 2008; Rekha et al., 2015).

1.3. Aquaculture in salt production areas

Salinas, i.e., solar saltworks, are mainly found in climate regions and have been shaping Mediterranean coastal landscapes for centuries (Walmsley, 1999; Balsas, 2016), within the boundaries of estuarine waters, intertidal marshes, brackish saline lagoons and coastal freshwater lagoons (Crisman, 2000). Salinas are highly modified natural and created coastal ecosystems, producing economically viable products (Korovessis and Lekkas, 2009) while playing a critical role in environmental conservation (Crisman et al., 2009).

Artisanal salinas in the Mediterranean have been in continuous decline since the 1950s (Petanidou and Dalaka, 2009), due to changes in the scale of fabrication (Sadoul et al., 1998); prime development land for urbanization, industrialization and tourism (Petanidou and Dalaka, 2009); lack of technological innovation (Coelho et al., 2015); lack of workforce (Balsas, 2016); changes in hydrological regimes (Coelho et al., 2015); and competition for aquaculture (Coelho et al., 2015). As a consequence, abandoned salt ponds have been filled in attempts to create new land for other uses. In Europe, salt ponds have been used for oyster culture in France, since the 17th century (Buestel, 2005); for fish culture in Sicily (Italy), though here most of the fish is reared in reservoir ponds used for the initial stages of salt making (Popescu, 2010); for fish culture in the Bay of Cádiz (Spain) (Yufera and Arias 2010); and also for fish culture in Aveiro, another saltscape in Portugal (Rodrigues et al., 2011). In Aveiro, during the 80’s and 90’s, fish farms replaced salt exploration at a rate of 13 salinas per year, but then the number and production of fish culture units decreased possibly due to lower investment and foreign competition (Rodrigues et al., 2011). In the Mondego estuary, fish farming increased when Portugal became an EEC/EU member and subsidies were attributed to aquaculture. Currently, local authorities are encouraging the implementation of aquaculture facilities as a mean of local socio-economic development.

The decrease in solar salt production compromises supporting, regulating, provisioning and cultural services in wetland areas, and the cultural identity of an entire generation (Cordeiro and Paredes, 2013; Crisman et al., 2009; Davis, 1999; Davis, 2000; Vieira and Bio, 2011). In recent years, attempts have been made to preserve solar saltworks and artisanal production and to raise awareness to the environmental, cultural and socio-economic importance of this ancient activity (Rodrigues et al., 2011). Simultaneously, aquaculture development has been promoted to support food needs and economic development (EC, 2009). As static water ponds, through the conversion of saltworks to aquaculture farms, are one of the most common water bodies used for aquaculture, the development of this activity in coastal areas is, in some cases, in conflict with salt production activities (Dalton et al., 2017) and wetland management and restoration (Yang et al., In Press). Local authorities have thus a dual problem: how to avoid the decline of solar salt production while promoting sustainable aquaculture development on its all facets: economic, social, environmental and cultural.

The current study is set within the boundary of the Figueira da Foz Municipality, in the Atlantic coastal zone of Portugal, which has been losing its saltworks since the 1970s (ZIR, 2011), and urges for an integrated management plan that considers both the aquaculture and the salt production activity. It proposes a MCDM approach to identify priority areas for semi-intensive and extensive aquaculture development in solar salt production areas. The method allows to estimate 1)