Ocean and Coastal Management 165 (2018) 268–279

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Selection of suitable coastal aquaculture sites using Multi-Criteria Decision Analysis in Menai Strait, UK

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ARTICLE INFO

Keywords:
Aquaculture
Site selection
Hydrodynamic simulation
Stakeholder participation
Multi-criteria decision analysis

ABSTRACT

The coastal areas are subject to increasing exploitation and diverse functions. The widely conducted aquaculture activities intensify the stress at the coastal areas and bring new challenges to aquaculture and sustainable coastal management. The suitable site selection is an optimistic way to minimizing stress on ecosystem, enhancing productive harvests, and mitigating conflicts between different water users. This study aims to demonstrate a local-oriented approach for selecting suitable locations for mussel cultivation in the Menai Strait by conducting Multi-Criteria Decision Analysis (MCDA), which takes environmental and socio-economic factors into consideration. A high resolution hydrodynamic model was built to overcome data scarcity by providing data sets. Interviews and a questionnaire survey were organized to engage local stakeholders into decision-making process. The result suggested two separated areas that suitable for mussel cultivation, which covers 20.5% of the whole region (8.8 km^2). The environmentally productive area differed significantly from socio-economically suitable area, which indicated that both categories of evaluation criteria need to be concurrently considered to achieve high production as well as prevent conflicts among stakeholders. This selection method provides a way to overcome data scarcity and engage local stakeholders, and its implementation has the potential to contribute to the sustainable coastal development by reducing potential conflicts among users at the planning stage.

1. Introduction

The fishery industry plays an important role in providing protein and essential nutrition to human beings as well as creating job opportunities for tens of millions of population. The aquaculture industry, as an important component of fishery industry, is the fastest growing food industry in the world (FAO, 2014). FAO indicated that world fish aquaculture production for food consumption expanded from 32.4 million to 66.6 million tons at annual increase ratio of 6.2 percent in average during the period 2000–2012. Moreover, productions by the capture fishery and aquaculture support the livelihoods of 10–12 percent of world's population.

The coastal areas are of diverse functions and crowded with different stakeholders, the widely conducted aquaculture activities intensify the stress at the coastal areas and bring new challenges to aquaculture management. A recent FAO survey suggested that the ecosystem approach to aquaculture (EAA) and spatial planning are important tools in achieving the sustainable aquaculture administration (FAO, 2013, 2014 and 2015). A good spatial plan is capable of minimizing stress on ecosystem, enhancing productive harvests and mitigating conflicts between different water users (Longdill et al., 2008). In the EU, the Blue Growth Strategy (EC, 2012) includes aquaculture and maritime spatial planning to support sustainable growth in the marine and maritime sectors.

The Spatial design software such as Geographic Information System (GIS) is commonly used for spatial planning of aquaculture, and different sets of feasible and local-oriented evaluation criteria are designed for identifying optimum alternative locations in order to improve local aquaculture situations (Nath et al., 2000; Dapueto et al., 2015). Since the late 1980s, studies on aquaculture site selection have increased, and selection methods applied to various places for practical governance. These studies were conducted for both shellfish and finfish (Parker et al., 1998; Rajitha et al., 2007), and their study areas involved inshore, offshore, lagoon and estuary regions (Ross et al., 1993; Perez et al., 2005; Rajitha et al., 2007). In recent years, the technology innovation and new research tools, such as satellite remote sensing, contributed to the establishment of a more comprehensive site-selection system (Radiarta et al., 2008; Saitoh et al., 2011, Liu et al., 2013, 2014a,b, Brigolin et al., 2015, 2017).

To achieve the sustainability of aquaculture development, the

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https://doi.org/10.1016/j.ocecoaman.2018.08.022
Received 7 February 2018; Received in revised form 26 July 2018; Accepted 21 August 2018

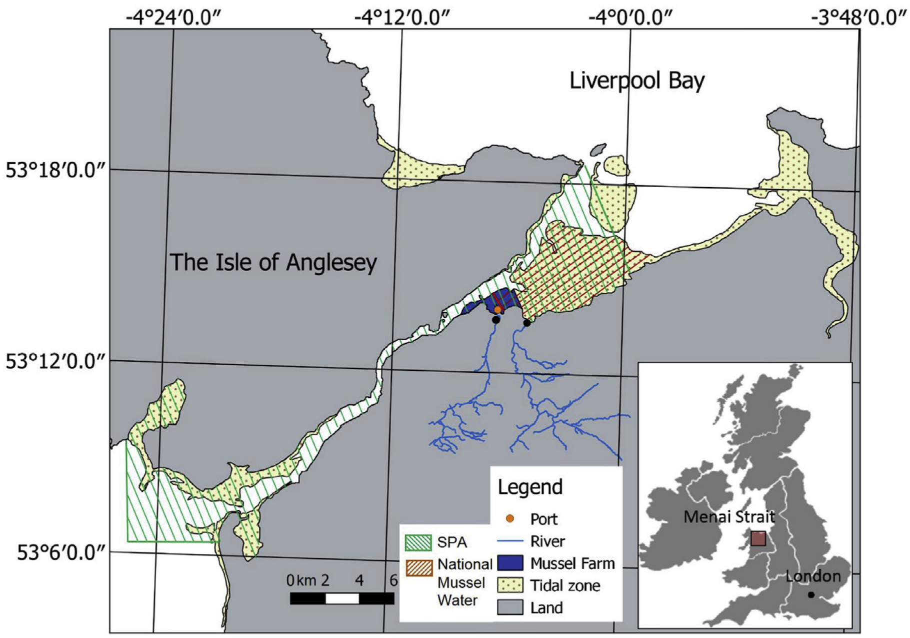

Fig. 1. The location of study area, Menai Strait. Yellow color refers the tidal zone, blue color refers to the location of current mussel farming area, red point refers the Port Penrhyn, two rivers from left to right are River Cegin and River Ogwen. (Source: Natural England Website: http://magic.defra.gov.uk/MagicMap.aspx). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

evaluation criteria were classified into three main pillars of sustainability, namely environmental, economical and social sections. In respect to environmental consideration, the common used criteria are physical conditions (e.g. sea surface temperature and salinity), topography (e.g. bathymetry and slope), food availability (e.g. concentration of chlorophyll-a, seawater volume, flushing and vertical turbulent mixing), and nutrition abundance (e.g. river runoff, distance from river mouth and chemical nature), as well as the local-oriented criteria involving suspended sediment concentration (SSC), impacts of climate change (e.g. El Niño, Southern Oscillation or Monsoon) and local conservation requirements (Radiarta et al., 2008; Liu et al., 2013, 2014a,b; Longdill et al., 2008; Silva et al., 2011). In regard to social-economic criteria, efficiency (e.g. access way and distances from infrastructures, markets and settlements), coexisting usages (e.g. tourism, commercial fishing and recreation), institutional factors (e.g. national land use policy, legal constrains, conservation areas, historical areas, seascape and etc.) are taken into account (Liu et al., 2013, 2014a,b; Longdill et al., 2008, Brigolin et al., 2015, 2017). Even though the previous studies have brought different types of criteria together and incorporated them into comprehensive site-selection methodologies, the considerations regarding relative importance among the criteria are still lacking. Data for selected criteria highly depend on observations and historical records, limiting the prediction accuracy of site selection.

The Multi-criteria Decision Analysis (MCDA) method, the basis of which is the analytic hierarchical process (Lahdelma et al., 2000; Belton and Stewart, 2002; Linkov et al., 2006), is adopted for building an evaluation framework in this study. MCDA methods can be used for quantifying benefits, risks and uncertainties in natural resource management (Mendoza and Martins, 2006; Fish et al., 2011) and spatial explicit land use models (Schaldach et al., 2011; Priess et al., 2011; Geneletti, 2013). Implementation of MCDA support the decision-making process, by considering an explicit set of criteria and their relative importance under a fully transparent process, while involving a wide range of stakeholder views to express a more societal perspective.

This study takes the mussel farming industry in the Menai Strait, UK as a case study. The eastern intertidal flat of the Menai Strait, Bangor Flat, is one of the most important blue mussel *Mytilus edulis* cultivation areas in UK, and its harvest varies from 7000 to 12,000 tons per year which occupies 60–75% of total UK cultivated mussel productions (MEP, 2010). With a high yield and rapid demanding growth of mussel production, the balance between mussel cultivation and other ecosystem services (e.g. migratory bird conservation) in this region become more fragile, which requires a local-oriented marine spatial plan to guide local mussel sites planning by predicting and mitigating potential conflicts in plan stage. To achieve a successful marine spatial planning, early engagement of local stakeholders and considering their local knowledge are of virtual importance (Gopnik et al., 2012; Collie et al., 2013; Flannery et al., 2018). As for a regional spatial marine planning for the Menai Strait, the engagement of diverse local stakeholders is needed and it will play a vital role in fostering a harmony and sustainable local development.

This study aims at demonstrate a method for selecting suitable mussel farm locations and to suggest alternative expanding locations for local shellfish cultivation in the Menai Strait by conducting Multi-Criteria Decision Analysis, which allows engagement of local stakeholders and consideration of environmental, social-economic and conservation factors into account. Given the scarcity of high-resolution data and the desire of engaging local stakeholders, the significance of this study are that: 1) provides a way to weight the importance of each selected criterion by considering the diverse interests of stakeholders; and 2) reduces the limitation caused by paucity of data sets by building a local scale high-resolution hydrodynamic model.

2. Material and methods

2.1. Study area

The Menai Strait is a narrow tidal channel that is located in the middle of the United Kingdom separating Anglesey Island from mainland Wales, refers to Fig. 1. Both ends of the Menai Strait are connected with Irish Sea. The northern mouth of this strait open to Liverpool Bay and the southern mouth open to Caernarfon Bay. The Menai Strait extends about 30 km with a mean width of approximately 800 m. The width varies from about 8 km at the north mouth to 300 m around the Menai Bridge (known as the Swellies). At the northern mouths, the bottom is mostly covered with sand and shingle that are exposed at low water, whereas the bottom in the narrow middle part of the channel is rocky and uneven, and water depth varies from a few meters to 8 m (Rippeth et al., 2002). Because of its unique topographical features, the Menai Strait is subject to the vigorous semi-diurnal tidal current. The reported current speed is up to 2.5 m/s in spring tide at both the narrowest channel and southwest mouth (Rippeth et al., 2002). The total