Journal of Environmental Management 181 (2016) 791–804

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Investigation of a novel approach for aquaculture site selection

Lynne Falconer*, Trevor C. Telfer, Lindsay G. Ross

Institute of Aquaculture, University of Stirling, Stirling, FK9 4LA, United Kingdom

ARTICLE INFO

Article history:
Received 7 February 2016
Received in revised form
7 July 2016
Accepted 8 July 2016
Available online 18 July 2016

Keywords:
Aquaculture
GIS
Maxent
Mahalanobis Typicality
Multi-criteria evaluation
Site selection

ABSTRACT

This study investigated the potential use of two "species distribution models" (SDMs), Mahalanobis Typicality and Maxent, for aquaculture site selection. SDMs are used in ecological studies to predict the spatial distribution of species based on analysis of conditions at locations of known presence or absence. Here the input points are aquaculture sites, rather than species occurrence, thus the models evaluate the parameters at the sites and identify similar areas across the rest of the study area. This is a novel approach that avoids the need for data reclassification and weighting which can be a source of conflict and uncertainty within the commonly used multi-criteria evaluation (MCE) technique. Using pangasius culture in the Mekong Delta, Vietnam, as a case study, Mahalanobis Typicality and Maxent SDMs were evaluated against two models developed using the MCE approach. Mahalanobis Typicality and Maxent assess suitability based on similarity to existing farms, while the MCE approach assesses suitability using optimal values for culture. Mahalanobis Typicality considers the variables to have equal importance whereas Maxent analyses the variables to determine those which influence the distribution of the input data. All of the models indicate there are suitable areas for culture along the two main channels of the Mekong River which are currently used to farm pangasius and also inland in the north and east of the study area. The results show the Mahalanobis Typicality model had more high scoring areas and greater overall similarity than Maxent to the MCE outputs, suggesting, for this case study, it was the most appropriate SDM for aquaculture site selection. With suitable input data, a combined SDM and MCE model would overcome limitations of the individual approaches, allowing more robust planning and management decisions for aquaculture, other stakeholders and the environment.

1. Introduction

One of the most important decisions for aquaculture is site selection as it provides the foundations not only for economic benefit, but also the sustainability, reputation and longevity of an individual farm and the industry as a whole. Site selection influences almost all aspects of aquaculture, including production and economic performance (Llorente and Luna, 2013), environmental impact (Wu, 1995), social acceptability (Katranidis et al., 2003) and the location may even have consequences for human health (Jang et al., 2006). As land and water are finite resources, space for aquaculture and competing industries is limited so it is vital that site selection is planned and managed appropriately. Unplanned development in the past has resulted in environmental, economic and social issues (Afroz and Alam, 2013; FAO, 2014; Suplicy et al., 2015) but even planned development can have negative consequences if insufficient information is available, plans are ill-defined and site allocation/selection is inappropriate for the species, system, community, other resource users and the environment. Decision support tools including spatial models are valuable sources of information when developing strategies and plans for development (Aguilar-Manjarrez et al., 2010; Ross et al., 2013). However, it is important to ensure the decision support tools and methodologies are both relevant and useful for the overall purpose and alternative approaches should also be considered alongside more established techniques.

Spatial modelling has been used to identify suitable sites for many different aquaculture species and systems throughout the world (Aguilar-Manjarrez et al., 2010; Ross et al., 2013) and one of the most common methods is the use of multi-criteria evaluation (MCE) (e.g. Buitrago et al., 2005; Salam et al., 2005; Radiarta et al., 2008; Hossain et al., 2009; Ross et al., 2011). The MCE approach combines multiple variables in a structured model (e.g. temperature, depth, distance to markets etc) using a weighted overlay where the weights are proportional to importance (Nath et al.,

* Corresponding author.
E-mail address: lynnefalconer1@gmail.com (L. Falconer).

http://dx.doi.org/10.1016/j.jenvman.2016.07.018
0301-4797/

2000). This is advantageous, as it allows assessment of the spatial variability of the biological, environmental, and socio-economic characteristics relevant to an aquaculture site, includes consideration of the different levels of importance amongst parameters and provides a qualitative and quantitative output which is useful and easy to understand for decision makers. However, development of such models requires knowledge not only of the species and systems but also their relationship with the relevant key parameters, so enabling reclassification to a common scale and assignment of weights. Model developers can employ their own experience and knowledge, values from literature and/or expert and stakeholder opinion within the process, but difficulties arise if there is disagreement or insufficient information to develop a robust model. Therefore in some cases an alternative approach which does not involve reclassification or weighting may be preferable.

“Species distribution models” (SDMs) are numerical tools which use observations of species occurrence or abundance together with environmental variables to predict probable species distribution across a study area (Elith and Leathwick, 2009). SDMs, habitat suitability models (HSMs), ecological niche models and bioclimatic envelope models all address similar issues and terminology can be confusing (Hirzel and Lay, 2008; Bradley et al., 2012). The term SDM is used in this study as it is one of the more popular terms. Generally, SDMs extrapolate species location data in space based on correlations of occurrence with selected environmental variables (Franklin, 2010). Their primary use is to explain or predict species distributions and the information provided can help with conservation planning, assist the understanding of evolution, predict climate change impacts and assess invasive species (Elith and Leathwick, 2009). However, recently, applications of SDMs have become more diverse and some studies have used them for other purposes, such as the estimation of the monthly probability of wildfires (Peters et al., 2013) and to map landslide susceptibility (Felicísimo et al., 2013).

Furthermore, Evans et al. (2010) suggested that presence-only SDMs show potential as a method to assess the suitability of geographic regions for biofuel feedstock production. Using similar logic, SDMs could be used to assess the suitability of an area for aquaculture production. Replacing the species location data with farm location data would allow the model to assess conditions at those sites, extrapolating the analysis to the whole of the study area to identify further areas that have similar conditions to the input farms and are thus also suitable sites for aquaculture.

Unlike the MCE approach, the use of SDMs requires no prior information on how farmed species are influenced by the variables and there is no need to reclassify data or establish weightings. The data needed are the location of the existing farms and spatial layers of key variables which are thought to influence the location of those farms. Consequently, the use of an SDM could provide an alternative option for site selection assuming that the selected farms used within the SDM process are in suitable locations for aquaculture and that similar areas could also be made available for development. The aim of this study was to investigate the potential use of two SDMs, Mahalanobis Typicality and Maxent, for aquaculture site selection.

2. Methodology

2.1. Study area and farm locations

The study area (total land area approximately 46000 km^2) was located in the Mekong Delta in Southern Vietnam (Fig. 1), which is the largest aquaculture production area in the country (Raux et al., 2006). Rapid growth of the Vietnamese aquaculture industry has occurred in recent years and the culture of pangasius (*Pangasianodon hypopthalmus*) is the most important sector in terms of production and value (FAO FishStat Plus, 2014). Pangasius farming occurs along two main branches of the Mekong River (Phan et al., 2009; De Silva and Phuong, 2011), however, the potential for expansion and development of new pangasius farms along the river is limited as there is competition with other users and land prices, which are expensive to begin with, continue to rise (Bosma et al., 2005; Phan et al., 2009). This area was selected as a suitable case study as alternative locations may be required for future aquaculture development.

Pangasius is an obligate air-breathing species that can tolerate high stocking densities (Phuong and Oanh, 2009) and environmental conditions that would otherwise be fatal to most aquaculture species (Belton et al., 2011). Consequently, it is farmed in highly intensive systems, with high production levels (De Silva and Phuong, 2011). Farms in the Mekong Delta typically consist of earthen ponds with an average water depth of 4 m and regular water exchange (Phan et al., 2009). As pangasius is a freshwater species, saline intrusion in the delta may impact production, particularly in the dry season. The dry season in the Mekong Delta lasts from December to April, with a rainy season from May to November (Sakamoto et al., 2009).

The locations of 192 pangasius farms (Fig. 1) were obtained from a survey conducted as part of the EU FP7 Sustainable Ethical Aquaculture Trade (SEAT) project (Little et al., 2009). SDMs require input points which normally represent the presence or absence of the studied species. In this study the input points represent the presence of an existing pangasius farm as the models will use this information to identify further similar areas based on the conditions at these locations. The surveyed farms were considered appropriate for use in the models as they had successfully produced at least one crop of pangasius and they were all located in the main area used for pangasius culture in Vietnam.

2.2. Models

In order to assess the potential use of SDMs as an alternative approach to MCE for aquaculture site selection, four models were compared; two SDMs and two MCE models. As there is almost always more than one way to construct an MCE model, two models were developed using different reclassification methods; a User-defined MCE model and a Fuzzy MCE model. Mahalanobis Typicality and Maxent were selected as two SDMs with a contrasting approach. The former considers the variables to be of equal importance, while the latter assesses the variables to identify the most important variables which explain the spatial distribution of the input points.

The main differences in required user/developer input for the MCE models and the two SDM models are highlighted in Fig. 2. Both MCE and SDM approaches require user input for data identification, collection and processing into layers for use in the models. The MCE approach also requires the user to design the model structure, reclassify the data and weight layers and submodels. With regard to SDMs, Mahalanobis Typicality needs no user input beyond the development of data layers, while Maxent has settings which must be adjusted depending on the scope of the work.

Further details on each modelling approach are found in their respective sections below. IDRISI Selva [Clarks Lab, Massachusetts, USA] was used as a modelling environment and each data layer was processed to have a spatial resolution of 30 m and georeferenced using the UTM reference system (UTM-48N).

2.2.1. Variables

Variables were selected after visits to the study area and discussions with aquaculture experts with experience of Vietnamese