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Understanding socio-ecological drivers of spatial allocation choice in a multi-species artisanal fishery: A Bayesian network modeling approach

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ABSTRACT

Effective management of artisanal fisheries requires understanding fishers, their behaviors, and the drivers that underpin their choices. Behavioral drivers are critical links in understanding the interactions between social and ecological systems and can help inform effective management approaches. A Bayesian Belief Network modeling approach was used to investigate a diverse range of qualitative and quantitative social and ecological drivers of spatial location choice in a multi-species artisanal dive fishery in Costa Rica. Empirical and observer data used to populate the BBN showed the influence of economic factors, environmental conditions as well as social interactions on the decision-making process of spatial location choice. Good governance scenarios represented by Responsible Fisheries Marine Areas Management were analyzed for both hookah and free diving methods to assess the effects of responsible fishing on the fishers and the fishery. Model based-scenario analysis suggests that management interventions should consider the fisher's potential behavioral responses in the context of environmental variability, dependence on cultural assets, and food security. The results show that there is a need to understand fisher's decisions based on broad socio-ecological system understanding and consider the environmental outcomes alongside food security and the cultural significance of different marine species to fishing communities.

1. Introduction

Fisheries systems are complex and adaptive [1–5] and to better understand these systems, multi-scale responses have to be explored with a socio-ecological systems (SES) perspective in mind. Modeling fisher interactions with the SES is one approach to help understand ecological responses [6]. For instance, undesirable regime shifts may be anticipated and potentially avoided if the behaviors of fishers, the institutions, and the ecological feedback were incorporated into management planning [7].

The literature around understanding fisher behavior primarily focuses on large commercial fleets [11], with a limited number of publications focusing on smaller, artisanal fisheries. However, small-scale artisanal coastal fisheries are widespread [8,64–68] and have great economic and social importance in developing countries. Artisanal fisheries are often a reliable and important source of income and animal protein for fishers and their families. Small-scale artisanal fisheries purportedly have a low impact on the ecosystems on which they depend due to the low intensity of fishing gears and practices compared to industrial fisheries [8]. Despite this, multi-species artisanal fisheries, particularly in tropical coastal zones, are characterized by large spatial and temporal variation in landings, a high variety of species, different fishing gear and fishing methods, dispersion of coastal landings sites, and high resource access uncertainty [9]. The diversity of artisanal fisheries makes their assessment and management complex especially when considering the multitude of linkages between social and ecological components of the fishery system [3–5,10,69]. Both resource dynamics and the response of fishers must be considered to adequately support management measures [20].

An aspect of artisanal fisheries that is particularly diverse and complex is understanding fisher entry–exit and location choice behavior. Evidence suggests that factors other than economic profit, such as lifestyle and tradition, may have greater influence on smaller fishing fleets than on larger commercial ones [12–16]. Economic and non-economic factors that influence fisher behavior can lead to differences in the observed choices made by individual fishers and the way fishers as a group (a fleet) allocate their effort in time and space [17]. Moreover knowledge of behavioral

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responses of fishers to reallocate fishing effort at a trip level represent crucial information for designing efficient management solutions and mitigating the effects of fishing activities on marine ecosystems [18] and will lead to improved understanding of the relationship between catch per unit effort and abundance [19].

Models of fisher behavior have been developed to gain insight into the relationship between effort and abundance. These models are based largely on the assumption that fishers choose locations that maximize their expected profit [21,22,18]. For example, Wilen et al. [18] developed a discrete choice model of a dive fishery for sea urchins, in which the diver's decision whether and where to dive could be predicted from information on weather, catch rates, and prices. In discrete choice models utility drives individual choice [23,24,17]. Simulations in individual based models have been used at vessel level to unmask patterns of effort allocation in space and time between fisheries [25–27]. Commercial fisheries are able to feed fisher behavior models with rich quantitative data (e.g., official log book data and vessel tracking devices information) in order to spatially map the utility of fishing at different points in time. This type of quantitative data is often absent in artisanal fisheries making it statistically difficult to map fisher utility.

Not only is data often scarce, fishers' behavior in artisanal fisheries, particularly in small-scale and indigenous fisheries [29,30], is also difficult to analyze and understand using the above mentioned models because social and cultural drivers are often highly influential in driving behavior [28]. Critical socio-cultural information is often qualitative in nature and can thus be more difficult to incorporate in econometric models [31–33]. The possibility of including socio-cultural drivers in a comprehensive modeling framework would help to reveal the linkages between non-material aspects of human well-being and ecosystem services such as fisheries resources [61,104].

Bayesian Belief Network (BBN) models are a suitable alternative modeling tool that has a reduced need for extensive quantative data. BBN models have been used to consider a wide variety of drivers influencing the decisions and choices of fishers [34,30] as these models are flexible and can account for subjective decision-making and qualitative reasoning [35]. Moreover, BBNs are particularly well suited to analyze decision-making because they allow the inclusion of causal and hierarchical dependencies. In addition, BBNs are easy to update as new information becomes available and it is possible to calibrate and validate these models [36]. BBN models fit well with the concepts of adaptive management [37] and can be a useful tool for organizing current thinking, generating testable hypotheses, and comparing alternatives [38]. The capability of BBNs to combine causal expert knowledge and empirical, evidence-based data [39] explains their growing importance in natural resource and environmental analysis [36,38,40].

This study investigates the location choice decisions of a multi-species artisanal dive fishery in Costa Rica. In this study location choice depends on the dive method used but also on the environmental characteristics of the site (e.g. visibility), specific features of the diving operation (e.g. day/night dive), economic factors (e.g. total catch value), catch composition and socio-cultural aspects (e.g. cultural values). A BBN approach is used to consider the diverse range of qualitative and quantitative environmental, economic, social, and geographic variables and to explore different management scenarios in this locally important artisanal fishery. We contextualize the results of BBN in the observational socio-cultural and economic information obtained from the face-to-face interview data and participatory observation.

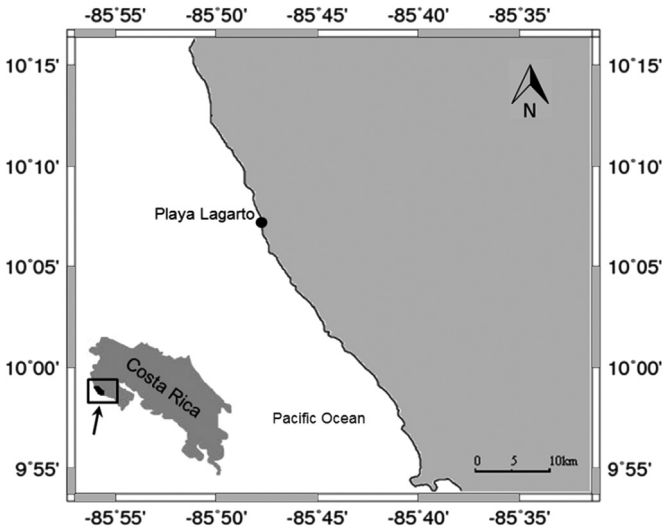

Fig. 1. Location of the Playa Lagarto fishing port in the province of Guanacaste, Costa Rica.

2. Material and methods

2.1. Description of case study area

The present study was conducted in Playa Lagarto (Fig. 1) located in the province of Guanacaste in Costa Rica (N 10 °07′23″, W 85°47′97″). Costa Rican bentho–demersal fisheries are primarily located in Pacific waters and 80% of the fleet is artisanal [41]. Naranjo and Salas [9] described more than 30 species caught by artisanal dive fishers. The marine area represents 0.16% of the world's ocean surface but harbors 3.5% of the known marine biodiversity [42,43]. The Costa Rican Dome (8–10°N, 88–90°W) is an area with high primary production that supports a high zooplankton biomass [44,45] contributing to the high biodiversity.

Artisanal ports along the coast are geographically dispersed and isolated and there is little monitoring of the fleet, leading to virtual open access conditions and the consequent risk of overfishing associated with open access fisheries [9,46]. For some species in the North Pacific regulations to control catch and effort do exist, for example the green lobster *Panulirus gracilis,* but regulations are not adequately enforced [47]. There is a lack of information on stocks and an absence of assessments of bentho–demersal species in this area. Exploitation patterns are also not completely understood. These fisheries therefore demand attention in order to define appropriated management approaches.

Dive-based fishing is influenced by environmental factors, such as high winds and water column turbidity and the artisanal bentho–demersal dive fishery in Playa Lagarto is no exception [48,49,9]. Fishers modify their fishing tactics with changing weather conditions and will, for instance, limit their effort to shallow and sheltered waters, or refrain from diving altogether on unfavorable days [9].

Aside from weather conditions, larger scale socio-economic drivers influence the decision to go diving, such as the poverty, and market conditions [50]. The availability or lack of alternative employment also influences fishing activity as it is often combined with traditional activities in the region, such as land clearing and maintenance, farming, and tourism [51]. A tradition of seafood consumption also influences diver behavior who will retain a share of the catch for subsistence. In this fishery from 2007 subsistence catch has ranged between 0.6% and 5.6% [9].

The most common dive fishing methods used in the Costa Rican fishery are hookah diving (H) and free diving (FD). Both fishing