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Sustainability of small-scale fisheries in the middle Negro River (Amazonas – Brazil): A model with operational and biological variables

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ABSTRACT

Fishing is a traditional and important activity in the Amazon Basin, mainly for low-income populations. Nevertheless, Amazonian fish diversity and abundance is threatened by several anthropogenic sources, including deforestation, hydroelectric dams, oil and gas development, global changes and overfishing. This article analyzes the proposal of an alternative model and discusses the predictions obtained from various scenarios and relates them to the management of commercial fishing in the region of the middle Negro River. The model was developed using Stella® 9.0, a software package based on system dynamics. Two scenarios were simulated to investigate the dynamics of the fish stock: (a) scenario I: considered a reduction in stock replacement values to half the initial values, a 50% increase in fishing effort, and variable costs and average monthly prices of fish, and; (B) scenario II: analyzed the effect of prohibiting commercial fishing. The planning horizon used was 120 months. Given the results achieved by the simulations, it would be interesting for authorities in the region to have effective control over fishing access and for users to be aware that these natural resources, even though renewable, are susceptible to depletion.

1. Introduction

Fresh water accounts for only 0.01% of the world's water and approximately 0.8% of the Earth's surface (Gleick, 1996; Dudgeon et al., 2006), and fresh water is home to thousands of species that contribute to food security (Brooks et al., 2016). Globally, at least 2 billion people rely directly on freshwater, such as lakes, rivers and wetlands, for their food supply. In many localities, particularly in rural communities, fish is a major source of protein (Béné et al., 2007; Dugan et al., 2010; Youn et al., 2014). In 2014, fisheries catches yielded approximately 12 million tonnes (FAO, 2016), and these fisheries support at least 21 million fishers, many of whom live in low-income countries and rely on these fisheries for subsistence. They are often the last resort when primary income sources fail due to economic changes and natural disasters (Lynch et al., 2016). In addition to other important benefits, such as recreation, cultural and even spiritual values, fisheries contribute to the diversity of species and ecosystems.

Fish ecosystems are complex and difficult to analyze; however, modeling the ecosystem can minimize some of these difficulties. One of the benefits of modeling is that it enables a mathematical framework to be used to integrate field data with ecological theory, allowing the problem to be understood and simulated through the use of different scenarios. Ecosystem simulation models are used to investigate possible environmental impacts on fish populations, and different models have been developed (Polovina, 1984; Deangelis and Cushman, 1990; Christensen and Pauly, 1992; Salvanes et al., 1992; Walters et al., 1997; Grasso, 1998; Walters et al., 2000; Fu et al., 2015; Storch et al., 2017). Nevertheless, the use of ecosystem modeling is relatively new in the Amazon. Souza

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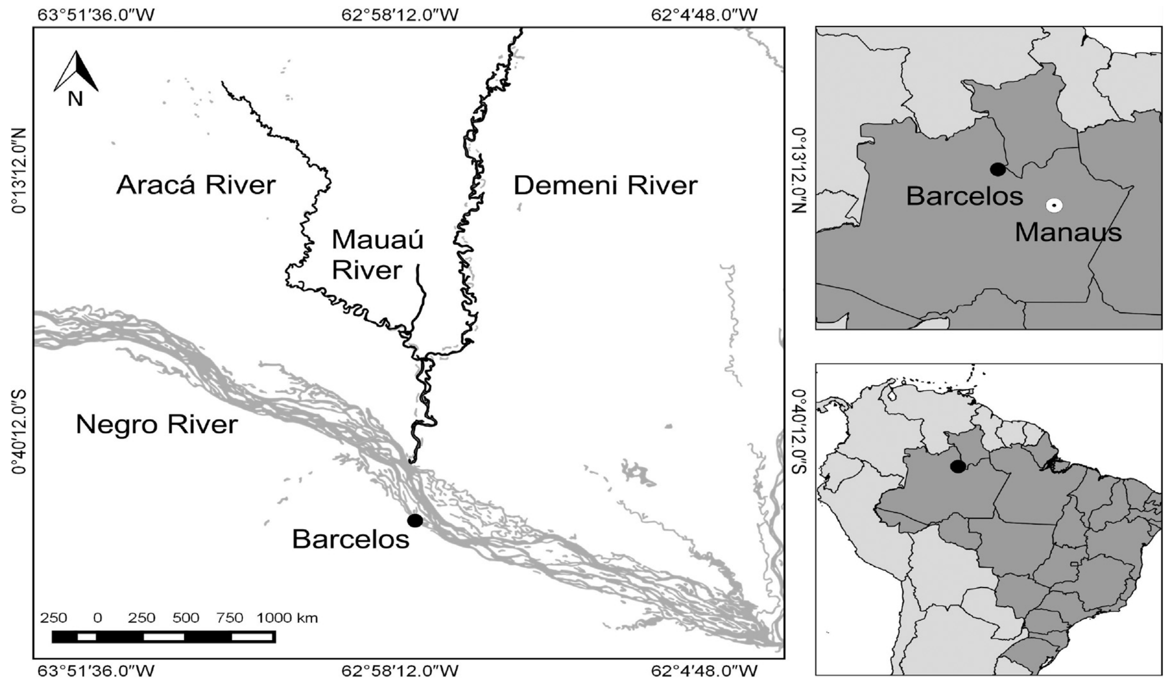

Fig. 1. Maps showing the study area; Map of South America showing Brazil; Map of the Amazonas State showing the municipality of Barcelos; Map the municipality of Barcelos showing the Negro, Aracá and Demeni rivers.

(2003) used this approach to assess the sustainability of subsistence fishing on a stretch of the Solimões River, taking into account the dynamics of the stock and fishing effort. Camargo and Petrere (2004) characterized the fishers and fisheries of the Tucuruí hydroelectric reservoir and created scenarios to predict situations of conflict over scarce resources. Souza and Freitas (2010) tested a predator-prey model, using humans as the predator and the fishing stock as the prey to evaluate fishing sustainability in the lower stretch of the Solimões River.

The Amazon Basin encompasses more than seven million km^2, which include an enormous and heterogeneous system of rivers, lakes, channels and streams. This ecosystem is home to the world's highest diversity of fish (Reis et al., 2016). Several anthropogenic factors, such as dam building (Kahn et al., 2014), oil and gas development (Finer et al., 2008), overfishing (Campos et al., 2015), invasive alien species (Latini and Petrere, 2004), deforestation (Lobón-Cerviá et al., 2015), and droughts caused by deforestation and global warming (Castello et al., 2013; Freitas et al., 2013), threaten this system.

The Negro River is the second largest tributary of the Amazonas River and is a typical blackwater river. It is known for its high diversity and low abundance of individual fish species compared with whitewater rivers (Barthem and Goulding, 2007). It contains approximately 950 described species, of which at least 35 are endemic. Much of the wealth generated in the municipality of Barcelos used to derive from the exploitation of ornamental fish, which accounted for over 60% of the municipality's income (Sobreiro and Freitas, 2008). However, this activity declined in recent years because of factors such as competition with other Amazonian regions and the retraction of the international market; thus, many fishers migrated to commercial fishing. In addition, more recently, fishers have switched to activities related to recreational fishing (Silva 2003; Sobreiro and Freitas 2008; Rivas et al., 2013). As in other regions in the Amazon basin, though fishers have other activities, such as subsistence agriculture and the extraction and commercialization of non-timber forest products (Sobreiro and Freitas, 2008; Rivas et al., 2013; Inomata and Freitas, 2015a), fishing is one of the most important economic activities for the population of the middle Negro River, who depend on fishing for their survival. Subsistence fishing is practiced by fishers in rural areas, primarily for their own consumption; distribution is secondary, and usually involves exchanges or small-scale sales.

This article analyzes the proposal of an alternative model and discusses the predictions obtained by scenarios that may influence the management of commercial fishing in the region of the middle Negro River. The model integrated the dynamics of fishers, which were influenced by economic factors, with the dynamics of the fishery resources, which considered the intrinsic characteristics of the three main groups of exploited species and the influence of the hydrological cycle.

2. Methods

2.1. Study area

The study was carried out in the middle Negro River region and focused on the municipality of Barcelos, which extends over an area of 122,450.769 km^2 (IBGE, 2015) in the northwestern region of the state of Amazonas (Fig. 1). The Negro River, which starts in the Junaí mountain range in Colombia, is the largest tributary of the Amazon River. It is approximately 1700 km long, and its basin extends over 715,000 km^2. The Negro River eventually joins the Solimões River to form the Amazon River; however, throughout its course, it drains low-lying areas and consolidated soils, which is reflected by its speed and erosion (Sioli 1984; Cunha and Pascoaloto, 2006).

2.2. Model

2.2.1. Data collection

Models are abstractions of reality, and they are unable to involve all the parameters in the modeled system since models sometimes require data with long time series; this translates into high costs, and in some situations, these data are inaccessible or nonexistent. In the present work, the developed model consisted of real data