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Fishing and drought effects on fish assemblages of the central Amazon Basin

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ABSTRACT

One method with considerable potential for understanding fishing and environmental impacts on fish assemblages is size spectra (SS) and diversity size spectra (DSS) analysis—a regression of Ln abundance or Shannon diversity against the natural logarithm of body size of fish assemblages. But the usefulness of this method for application to tropical freshwater fish assemblages is uncertain. Here, we assessed the extent to which SS and DSS analyses explained changes in the exploited fish assemblage related to fishing effort and river droughts. To do this, we used correlation analyses on historical datasets of river water level, fishing effort, and fish length measurements for 56 fish species in three of the largest rivers of the Amazon Basin. In calculating the SS and DSS analysis statistics, we found that linear regressions adjusted well to the diversity and Ln(abundance) data plotted against Ln(fork length). In analysing SS and DSS statistics in relation to fishing and environmental impacts, we found that the slope of SS was negatively correlated to drought intensity with a lag of zero years in all rivers. The slope of SS also was negatively correlated to fishing effort with a lag of three years in two rivers and a lag of two years in one year. The slope of DSS was not correlated to drought intensity and fishing effort in any of the rivers. Our results provide support for the use of SS analysis to investigate fishing and environmental effects on exploited fish assemblages in tropical freshwater environments.

1. Introduction

There is an increasing need to understand and mitigate the impacts of fishing on marine and freshwater ecosystems (Fogarty and Murawski, 1998; Jackson et al., 2001; Pauly et al., 2002). A promising approach to the current fisheries crisis is ecosystem-based fisheries management (Pikitch et al., 2004), which is inspired by recognition that maintaining healthy marine ecosystems is fundamental to the fisheries they support. Although of relatively recent origin, ecosystem approaches are becoming a routine part of fisheries assessment and management (Garcia and Cochrane, 2005; Tegner and Dayton, 1999). New methods to identify anthropogenic effects on exploited fish assemblages and ecosystems are being tested and developed.

Body size influences many ecological processes, from individual rates up to the structure of food webs and the provision of ecosystem services such as food (Blanchard, 2011). Given the importance of body size of individuals, one approach with considerable potential for understanding fishing impacts on fish assemblages is size spectra (SS) analysis: a regression of logarithmic abundance against the logarithmic body size of fish assemblages. SS analysis is based on the idea that the biomass and numbers of individuals of all species in a system decrease log-linearly with increasing body (Blackburn and Gaston, 1994, 1997, 1999; Pope and Knights, 1982). The slope and intercept of SS can be compared over time or across different conditions. Differences in slopes have been interpreted in terms of differential mortality rates and trophic transfer efficiencies. For example, an increase in the slope of SS can be attributed to an increase in the abundance of small-sized individuals relative to larger individuals (Dulvy et al., 2004). Interpretations that changes in fishing mortality cause changes in the slope and intercept of SS are supported by fisheries simulations (Gislason and Rice, 1998), data from the North Sea (Gislason and Rice, 1998) and a number of regions globally (Bianchi et al., 2000).

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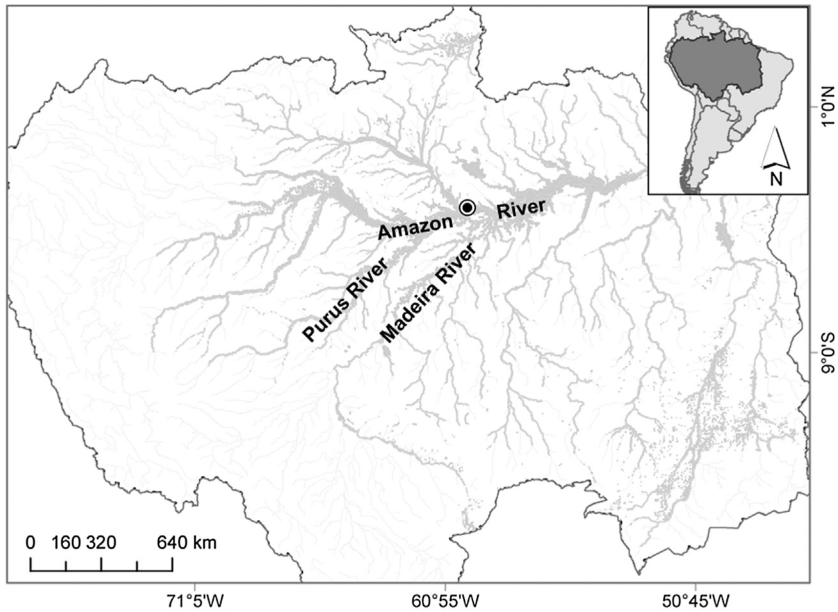

Fig. 1. The Central Amazon region, showing the city of Manaus (State of Amazonas, Brazil)where fishery-landing data were collected, and the Amazon, Madeira, and Purus Rivers where the fishing fleet routinely works.

Another related but less tested method is Diversity Size Spectra (DSS) Analysis, which computes species diversity across different body sizes (Hutchinson and MacArthur, 1959). As in SSA, DSS analysis is based on the idea that typically there are few large individuals within species and few large-bodied species (Rice and Gislason, 1996). DSS analysis can be used to assess changes on the overall composition of sizes encompassed by different species in a system.

The SS and DSS of fish assemblages can be expected to respond to fishing and environmental changes in direct and indirect ways (Daan et al., 2005; Piet and Jennings 2005). For example, the proportionally greater removal of larger individuals, which is a common effect of fishing, is expected to lead to increases in the slope of SS while also causing compensatory effects on small fish, which in turn may lead to further increases in the slope of SS. The time scales and mechanisms behind these responses remain unclear due to the difficulty of understanding whole assemblage dynamics. For instance, lags of six to 12 years between fishing effort and the slope of SS have been documented in the North Sea (Daan et al., 2005). One factor that can explain the lag of assemblage responses to fishing or environmental changes is age of recruitment to the fishery. Environmental conditions during larval and juvenile stages typically have profound effects on the biomass and abundance of the resulting cohorts growing to adult stages or recruiting to the fishery (Fuiman and Werner, 2002).

Despite its promise, the reliability and usefulness of SS and DSS analyses in freshwater ecosystems have not been tested, as to date all SS and DSS analyses have focused on marine ecosystems (Murry and Farrell, 2014). It is not clear if SS analysis works in tropical fish assemblages, particularly in regions where data are scarce (Bianchi et al., 2000; Murry and Farrell, 2014). An analysis of SS of tropical demersal fish assemblages across different latitudes showed consistent responses to differences in ecosystem productivity and exploitation levels (Bianchi et al., 2000). But that study found non-conclusive results as to the extent to which the slope of SS reflects changes in exploitation levels of tropical fish assemblages facing environmental noise.

Here, we applied SS and DSS analyses to a comprehensive dataset on the fish assemblage exploited by fisheries in the Amazon Basin in order to address the following research questions: Do river droughts (i.e. low water levels) and fishing effort influence the SS of the fish assemblage? Do river droughts and fishing effort influence the DSS of the fish assemblage? And, what is the lag of possible drought and fishing effort effects on the SS and DSS of the fish assemblage?

2. Methods

We applied SS and DSS analyses to an 11-year dataset of multigear, multispecies fish catches in three of the largest rivers of the Amazon Basin. The data were based on landings recorded in Manaus, Brazil, totalling 58,047 fishing trips and 299,857 length measurements of 56 different fish species or taxonomic groups. The slopes of annual SS and DSS were assessed by means of correlation analyses in relation to annual indices of fishing effort and river drought conditions.

2.1. Study area, fishes, and fisheries

The study area comprised the Madeira, Purus, and Amazon (which here includes the Solimões) Rivers (Fig. 1). The ecosystem in these rivers is the várzea river-floodplain – a complex mosaic of seasonally inundated rain forests, lakes, and winding channels formed by the seasonal and predictable flooding of river waters stemming from the Andes Mountains (Irion et al., 1997). On average, river water levels begin to rise around December, reaching their maximum level around June, at which time they begin to drop, reaching their lowest level in October. Average seasonal water level variation in the study area during the study period was 12 m.

Many Amazonian fishes have evolved seasonal migratory strategies to exploit resources in the floodplains that are not available to them in river channels (Fernandes, 1997; Hermann et al., 2016; Winemiller and Jepsen, 1998). Many fish species migrate to the floodplains when water levels overflow river channels and flood adjacent floodplains, where they feed on abundant plant-based food resources and find protection from predators (Castello, 2008; Goulding, 1980). The decline of water levels forces fishes to migrate out of the floodplains back to river channels and floodplain lakes, where fishes are more vulnerable to natural predators and fishing gear (Nolan et al., 2009; Welcomme, 1985). Natural mortality in floodplain lakes during low water levels (i.e. dry season) is gener-