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Seasonal and interannual dynamics of river-floodplain multispecies fisheries in relation to flood pulses in the Lower Amazon

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ABSTRACT

River-floodplain fisheries are highly productive as seasonal water level changes, known as 'flood pulses,' increase the productivity of fish populations by providing them with feeding and reproductive opportunities in the floodplains. However, current understanding of flood pulse effects on fisheries activities at seasonal and interannual time scales remains deficient. Here, we analyze a comprehensive dataset of the Lower Amazon region to address the following questions: How flood pulses affect river-floodplain fishing strategies with respect to species composition and habitat? What is the interannual lag of hydrological effects on fisheries yields? And does that lag depend on the life-history strategy of the target fish species? A principal coordinates analysis indicated that fishing activities followed a clear seasonal pattern characterized by alternating habitat and species. Cross-correlation analyses indicated the existence of positive effects caused by mean water levels on fish catches roughly two or three years later. The lag of such water level effects on fish catches was proportional to species longevity, being 22 months for short-lived species with a mean age at catch of 21 months, 26 months for medium-lived species with a mean age at catch of 27.2 months, and 42 months for short-lived species with a mean age at catch of 33.7 months. The results of this study highlight the large seasonal and annual variability of tropical river-floodplain fisheries, and underscore the dependence of fish catches on natural river hydrological cycles. Because these fisheries are suffering increasing exploitation pressures, conservation measures are necessary to protect the hydrology of Amazonian rivers.

1. Introduction

River-floodplain fisheries are highly productive as seasonal water level changes, known as 'flood pulses' (Junk et al., 1989), increase the productivity of fish populations by providing them with key feeding and reproductive opportunities in the floodplains (Bayley, 1995; Welcomme, 1985). Most river-floodplain fisheries occur in tropical and sub-tropical regions, where fish species diversity is high and the human populations depending on fisheries have few livelihood alternatives (Bene et al., 2009; Welcomme et al., 2010). Yet, current understanding of flood pulse effects on the dynamics of fish populations and related fisheries activities remains sparse (Welcomme and Halls, 2004).

Floodplain fish species have developed physiological adaptations, life-history strategies, and reproductive and feeding behaviors to cope with, and take advantage of, flood pulses (Lowe-McConnell, 1975; Welcomme, 1979; Bunn and Arthington, 2002). Flood pulses primarily change the availability of habitats for fish populations. Rising water levels make available grass fields, shrubs, forests, and macrophyte habitats that provide fish with abundant food items and excellent nursery conditions. Intensive feeding during high waters permit fish to build fat reserves that support them during low waters, when food is scarce and they have to develop their gonads for spawning early during high waters (Poulsen et al., 2004).

The migratory behavior of fish in floodplains appears to be closely linked to reproduction and changes in river water levels (Bunn and Arthington, 2002). Many fish species migrate laterally from floodplain lakes or river channels onto vegetated floodplain habitats and stay there until water levels are maxima or receding waters force them to migrate back to river channels or floodplain

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lakes (Cox Fernandes, 1997; Castello, 2008a,b; Arantes et al., 2013). In floodplain lakes, fish often suffer high natural mortality rates during low waters due to high temperatures and/or low oxygen levels (Junk et al., 1983; Welcomme, 1985; Matthews and Marsh-Matthews, 2003). Many species return to river channels at this time, and some of them migrate longitudinally upstream, often hundreds or even thousands of kilometers to spawn or search for new habitat (Ribeiro and Petrere, 1990; Goulding, 1980). These seasonal changes in water levels and fish habitat affect the catchability of fishing gear. Most gear generally possess low catchability rates during high waters due to great expansions in flooded area, and high catchability rates during low waters as fish are concentrated in floodplain lakes or are caught in migratory schools when they migrate out of the floodplains or upstream in river channels (Halls and Welcomme, 2004).

Interannual variations in flood pulses can affect fish recruitment, growth, and mortality, thereby causing changes in fish biomass available for harvesting (Welcomme and Halls, 2004; Bailly et al., 2008). Years with intense high waters generally offer more feeding opportunities, increasing fish biomass available for harvesting in near-future years. Conversely, intense low water years can reduce fish biomass through increased natural or fishing mortality (Welcomme, 1985). As such, previous studies have found correlations between high or low water intensity in one year and fisheries catches in later years in Africa (e.g. Welcomme, 1979, 1985; Moses, 1987; Laë 1992, 1995) and the Amazon (de Mérona and Gascuel, 1993; Castello et al., 2015). Fisheries dynamics in river-floodplains is thus controlled by seasonal and interannual variability in water levels.

However, most studies on multispecies river-floodplain fisheries have focused on seasonal variability in overall fish catches, seasonal fishing patterns of a few target species, or the year-round species composition of the fish catch (e.g. Batista et al., 1998; Craig et al., 2004; Vallejos et al., 2013). To our knowledge, no study has investigated how flood pulses affect fishing strategies with respect to species composition, habitat, and seasonal effects. Several opportunities for fishing exist in tropical river-floodplains, as fish populations exhibit a diversity of life-history strategies and habitat availability varies geographically and temporally following the seasonal rise and decline of water levels. Furthermore, although previous studies have identified interannual flood pulse influences on fish catches, to date only a few studies have systematically quantified the lag between flood pulses and fishery yields. Flood pulse influences on fishery yields can be expected to mainly act on spawning and recruitment success (Freitas et al., 2012), because environmental processes occurring during the early life stages generally have profound influences on fish population dynamics (Fuiman and Werner, 2002). The effects of such phenomena should be noticeable in fishery catches after the time it takes for fish eggs and larvae to recruit to the fishery. Two- and three-year flood pulse lags affected fishery catches of all species together in the Central and Lower Amazon Basin regions, and similar lags were found for fish catches grouped in feeding groups in the Lower Amazon (de Mérona and Gascuel, 1993; Castello et al., 2015). This sort of lag of flood pulse influences on fishery yields is expected to depend on the life history and mean age at catch of the targeted species. Such lags are expected to be greater for large-sized species with slow growth, late maturation, and long life-span (i.e., K-strategists) than for small-sized species with high growth and mortality rates, early maturation, and short life-span (i.e., r-strategists).

Fisheries management requires improved understanding of seasonal and interannual variability in river-floodplain fisheries, particularly as a generalized paucity of data has impeded advances on the topic. These fisheries are suffering increasing exploitation pressure and the hydrology of the ecosystems that sustain them is becoming increasing altered by dam construction and land cover changes (Welcomme et al., 2010). The effects of altered flow regimes on tropical aquatic fishes are predicted to be stronger than those caused by changes in temperature induced by climate change (Meisner, 1992; Poff et al., 2001). These effect will be species-specific (Ficke et al., 2007), so they will depend on the life-history strategies of the species involved.

Here, we analyze a comprehensive dataset on multispecies fisheries of the Lower Amazon region to examine how hydrological variability affect populations of fish species with different life-history traits and how such effects impact fishing activities. We address the following research questions: (1) How flood pulses affect river-floodplain fishing strategies with respect to species composition and habitat? (2) What is the interannual lag of hydrological effects on fisheries yields? And (3), does the lag of hydrological effects on fishery yields depend on longevity and mean age at catch of the target fish species?

2. Methods

2.1. Study area

This study was done based on data collected from the fishing fleet of the Lower Amazon region (Isaac et al., 2008), in a 550 km stretch of the Amazon river-floodplains, between the cities of Almeirim, State of Pará, and Parintins, State of Amazonas, Brazil (Fig. 1). The ecosystem is classified as *várzea*, which are river-floodplains influenced by nutrient- and sediment-rich waters stemming from the Andes Mountains in the Amazon Basin (Sioli, 1968.). Fishing occurs in a variety of habitats, including river channels, which are the deepest habitats, and a series of progressively shallower habitats in the floodplains, including connecting channels, lakes, herbaceous fields, shrubs, and forests (Hess et al., 2003). These habitats are seasonally inundated by flood pulses of 6.2 m on average in amplitude, with a maximum water level in May-June and a minimum in October (Fig. 2a). Fisheries in the study area sustain per capita fish consumption rates of 40–94 kg yr^{-1}, well above the global average of 16 kg yr^{-1} (Isaac and Almeida, 2011).

2.2. Data collection

The fisheries data were collected between January 1993 and December 2004 in nine cities (Fig. 1) through daily interviews (Monday-Saturday) conducted with boat masters or the fishers themselves at the moment of landing. Data collected for each fishing trip included vessel type (wooded motorized boat or wooded canoe, with average 11 m length), number of fishers, number of days spent fishing, fishing gear used, habitat of fishing (i.e. floodplain lake or river channel), and total catch in weight for each species. Fish species were identified by their local common names, some of which encompass groups of species (Table 1). Respective daily river water level data measured at Óbidos (Fig. 1) was obtained from ANA (2015).

2.3. Data analyses

The original dataset included fishing trips in which a variety of fishing gears and vessel types and sizes were employed. The data were filtered to include only fishing trips made by motorized boats using gillnets to reduce variance caused by different catchability rates among different vessel and gear types. The resulting data of fishing trips made by motorized boats using gillnets included 54,798 fishing trip records that contributed with 52% of total fisheries catches during the study period. Catch (kg) and fishing effort (number of fishers × days spent fishing) were calculated for every fishing trip and summed per month to create a balanced sample design. Because the variance of catch increased with effort, catch