BOLETIM DO INSTITUTO DE PESCA

ISSN 1678-2305 online version

Scientific Article

ECOSYSTEM INDICATORS OF A SMALL-SCALE FISHERIES WITH LIMITED DATA IN MADEIRA RIVER (BRAZIL)

Carolina Rodrigues da Costa DORIA[1]

Maria Alice Leite LIMA[1]

Ronaldo ANGELINI[2]

[1] Universidade Federal de Rondônia - UNIR, Departamento de Biologia, Laboratório de Ictiologia e Pesca, Rodovia BR 364, Km 9,5, CEP 76801-059, Porto Velho, RO, Brasil. E-mail: carolinarcdoria@unir.br (corresponding author).

[2] Universidade Federal do Rio Grande do Norte - UFRN, Departamento de Engenharia Civil, Avenida Senador Salgado Filho, 3000, Lagoa Nova, Natal, RN, Brasil.

Received: November 13, 2017
Approved: April 10, 2018

ABSTRACT

This work presents an indicators-based analysis of a small-scale fishery operating in the middle Madeira River (Brazil), a tributary of Amazon River. We used landing species (kg) recorded daily by the Porto Velho fishermen's colony from 1990 to 2009, with total length recorded in five selected years. The species were classified by trophic level, and the Fishing-in-Balance, L index, and size class distributions were calculated. In addition, differences in yearly total landings (kg) were correlated with the Madeira river water level (cm). The average annual catch was 566.5 tonnes (± 193.6), with significant variation between the years not correlated to the river water level. The ecosystem indicators showed a stable tendency, with oscillations in the latter years reflecting an increased catch of higher trophic level and larger species. Fisheries managers in data-limited regions should consider these indicators for fish stock analyses to be low cost, practical, and easy to calculate.

Key words: limited data; fisheries; amazon region; size spectra; trophic level.

INDICADORES ECOSSISTÊMICOS DE UMA PESCA DE PEQUENA ESCALA COM DADOS LIMITADOS NO RIO MADEIRA (BRASIL)

RESUMO

Este trabalho apresenta uma análise baseada em indicadores para pesca de pequena escala que opera no médio rio Madeira (Brasil), afluente do rio Amazonas. Foram utilizados dados de desembarques diários da Colônia de Pescadores de Porto Velho que registrou a produção das espécies (kg) capturadas entre 1990 e 2009 e o comprimento total durante cinco anos. As espécies foram classificadas por nível trófico, e foram calculados o balanço na pesca, índice L e as classes de tamanho. Além disso, as diferenças nos desembarques totais anuais (kg) foram correlacionadas com o nível da água do rio Madeira (cm). A captura anual média foi de 566,5 toneladas (± 193,6), com variação significativa entre os anos e não correlacionadas com o nível da água do rio. Os indicadores do ecossistema mostraram uma tendência estável, com oscilações nos últimos anos, refletindo maior captura de espécies com maiores comprimentos e nível trófico. Os gestores de pesca em regiões com dados pesqueiros limitados podem considerar esses indicadores para análises de estoque de peixes como de baixo custo, práticos e fáceis de calcular.

Palavras-chave: dados limitados; pesca; região amazônica; espectros de tamanho; nível trófico.

INTRODUCTION

Inland fisheries tend to be less regulated in developing countries, and appropriate statistics and landing data are often lacking. Freshwater fisheries are often located in remote places with non-definable landing sites. Such fisheries are exploited by a large and diverse population of small-scale fishermen, with highly variable seasonal catch and species composition. Much of the catch does not enter a formal market system, going directly to domestic consumption; and many countries lack the resources for fisheries monitoring and assessment (APEL *et al*., 2013; GRANTHAM and RUDD, 2015; SANTOS *et al*., 2016).

Most studies published to date address industrial marine commercial or large-scale fisheries (ESCOBAR, 2015; INOMATA and FREITAS, 2015). For many inland regions such as the Amazon, the condition of fish stocks remains unknown, especially in tributaries distant from fishing and main consumer markets (LIMA *et al*., 2012; INOMATA and FREITAS, 2015). Comparisons among indicators of stock the status are important tools to highlight features and differences and offer insight into pressures on fisheries (BLANCHARD *et al*., 2010). The lack of robust data in Brazilian fisheries, in particular, has been recognized as a threat to stock management and conservation (RUFFINO, 2014).

Various approaches have been used to estimate the size and status of stocks in data-limited fisheries (PAULY *et al*., 1998; BLANCHARD *et al*., 2005; APEL *et al*., 2013). Among these, catch-based methods and direct counts of landings at markets are the most common (CARRUTHERS *et al*., 2014). These two methods provide information on variation in the catch, composition, and fishery unit effort, but are of limited use for understanding the general status of the stocks (CARRUTHERS *et al*., 2014; WELCOMME *et al*., 2014). By contrast, population and community metrics are potentially useful indicators of status of a fish stock due to their theoretical foundation and practical utility (BLANCHARD *et al*., 2005). Some of these indicators could be meaningful in a management context, as they compare observed patterns of ecosystem structure and function over time to the expected theoretical patterns in other systems. Useful ecological indicators include species-based and size-based metrics (average weight of an individual, average maximum size, and slope of the size spectrum), as well as trophodynamic and production indicators (LIBRALATO *et al*., 2008; BLANCHARD *et al*., 2010; FABRÉ *et al*., 2017).

The "size-spectra" approach plots linear regressions of the natural logarithm of fish species abundance vs. length classes over time, evaluating changes in slope and intercept parameters (RICE and GISLASON, 1996). These parameter values could represent changes in community structure and are proportional to the change in fishing intensity or environmental influences (GISLASON and RICE, 1998; BLANCHARD *et al*., 2010; FABRÉ *et al*., 2017). In addition, mean trophic level catch can be used to evaluate changes in the food web in various ecosystems around the world (PAULY *et al*., 1998). This indicator can be accompanied by the "fishing-in-balance" indicator, which evaluates whether changes in catch correspond to changes in the mean trophic level of the catch (PAULY and CHRISTENSEN, 1995; PAULY *et al*., 2000). Finally, trophic web interactions analysis quantifies loss in production, and provides the basis for defining the L index (LIBRALATO *et al*., 2008), a metric that takes into account both ecosystem properties (primary and secondary production and transfer efficiency) and features of fishing activities (trophic level of catches and primary production required).

It is essential to understand the small-scale inland fishery dynamics and the status of the stock in the tributaries of Amazon River, given the large socioeconomic impact of fishing to the region (ANGELINI *et al*., 2006). In this work, we combined data on ecological indicators to test 1) whether the catches in middle Madeira River during the period of 1990 to 2009 were stable and sustainable, and 2) whether community and ecological indicators can be combined to provide a useful method for analysis of the status of fish communities in data-limited regions in the Amazon.

METHODS

The Madeira River is the largest tributary of the Amazon River, at approximately 3,315 km^2 in area (GOULDING, 1979). Its headwaters are in the Bolivian Andes region, and it runs through Brazil, Bolivia, and Peru. The fishing activity carried out in the Madeira River, is characterized as a small-scale, multispecies fishery and is of high socio-economic importance for the local riverine community (DORIA and LIMA, 2015). In 2009, there were 1,200 registered fishermen across this region. The fishing fleet consists mostly of small wooden fishing vessels (non-motorized and motorized canoes; more than 1,000 units) and a few fishing boats. Non-motorized and motorized wooden vessels (average length 5.8 m) are used for fishing and for transporting fish. Non-motorized canoes are smaller than motorized canoes regarding storage capacity (250 and 600 kg, respectively). Larger fishing boats are motorized (average size 9 m ± 2.3 m), with larger storage capacity (average 2,500 kg) and use ice as the main form of fish preservation.

Most of the Madeira River fisheries occur in the Porto Velho city area (~200 km river stretch) and the fish landings occur in the Porto Velho fish market (average total landings 755 tonnes $year^{-1}$; DORIA *et al*., 2012), in the state of Rondônia, which is located in the northwest Amazon region (Figure 1). This market is managed by the Porto Velho Z-1 fishermen's colony, a which registers the fisheries information based on species catch and respective biomass (kg) daily. The information recorded by the fishermen's colony from 1990 to 2009 was used as the basis for this study. A colony staff measured the weight of each species landing, and the total length of each species was recorded by researchers at the same local daily over five years (1996, 2001, 2004, 2009, and 2010). Sampling was randomized considering a minimum of 40 specimens of each species with different sizes per day. The total fish catch was correlated with the Madeira River water level (in cm) in Porto Velho (Source: Companhia de Pesquisa de Recursos Minerais - Mineral Resources Research Company), using the Pearson test. The number of active fishing boats per year in the region was obtained, by oral interviewed, with one association representative and confirmed with three key local fisher.

Registered fish were cataloged by the colony employees under common names; subsequently, researchers categorized to the catch to the species level when possible based on QUEIROZ *et al*. (2013). The Shapiro-Wilks test revealed that data were not normally distributed ($W=0.749$, $p<0.01$), so non-parametric Kruskal-Wallis tests were performed to measure the yearly differences in yield (kg). We also performed a linear correlation analysis (Pearson coefficient) with catch tons to water levels, accounting for lag time as needed. Analyses were performed in statistical program R (R CORE TEAM, 2011). The relative frequency of the species landed was calculated for each species, with species comprising at least 2% of the total weight catch in the year being considered main species. Data were grouped into five-year bins (1990-1994; 1995-1999; 2000-2004, and 2005-2010).

The trophic level (TL) of each species was based-estimated from stomach contents (n=2,502) of fishes collected in the same area during

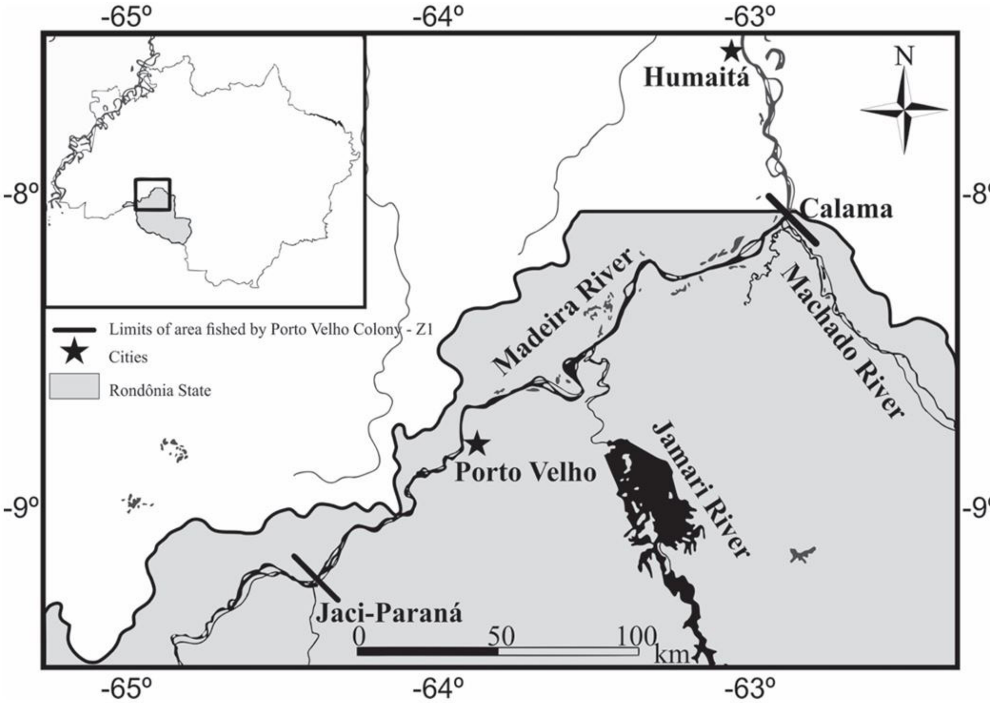

Figure 1. Location of the fishing area of Porto Velho Fishermen's colony Z1, in Porto Velho city, Rondônia State (in gray), Amazon, Brazil.

2009-2013 by the Laboratory of Ichthyology and Fisheries (LIF) of the Federal University of Rondônia in experimental fisheries and commercial fisheries. In the experimental fisheries the LIF used a set of 13 gill nets (mesh sizes from 30 to 200 mm between opposite knots) to guarantee greater amplitude of size by species in the samples (see details in: CELLA-RIBEIRO *et al*., 2016). The TL values were estimated as follows: TL = 1 for all primary producers and detritus; for consumers, TL = 1 + a weighted average of the trophic level of prey. The Annual Trophic Level was estimated (CHRISTENSEN *et al.*, 2005) by weighting the landing of species ((species catch / total catch) * TL of species)). Considering that, in ecosystem evaluation of the fisheries, the functionality of the species is more relevant than the species itself, to analyze TL dynamics, species were grouped into four categories, ranging from detritivores to carnivores: 2.0 to 2.49; 2.5 to 2.99; 3.0 to 3.39; 3.4 to 4.0

The Fishing-in-Balance (FIB) index (PAULY *et al*., 2000) was calculated to assess whether changes in the average trophic level reflect changes in catches using the equation:

$$F_iB_k = \log\left(Y_k\left(\frac{1}{TE}\right)^{TL_k}\right) - \log\left(Y_0\left(\frac{1}{TE}\right)^{TL_0}\right) \quad (1)$$

where: k = year (0 = baseline year of 1990), Y = catch (tonne), TL = mean trophic level of the catch, and TE = transfer efficiency between trophic levels, set to 0.1, a mean derived from 48 ecosystem models (PAULY and CHRISTENSEN, 1995).

The L index (LIBRALATO *et al*., 2008) can be expressed as a function of the primary production required (PPR) to support the catch of each species caught, the trophic level (TL) of these species, primary production of the base chain (P1), and the energy transfer efficiency rate (TE) of trophic flows in the ecosystem:

$$L = -\frac{1}{P_1 \cdot L_n TE} \cdot \sum_i^m \left(PPR_i \cdot TE^{TLi-1}\right) \cong -\frac{PPR \cdot TE^{TLc-1}}{P_1 \cdot L_n . TE} \quad (2)$$

where: 1, PRI, and TE values were estimated using a food web model (Ecopath approach) for this stretch of Madeira River (LIMA, 2017). In a sustainability fishing reference values for L index would be between 0.021 and L = 0.007 (LIBRALATO *et al*., 2008).

The species were classified as long-distance migrators, mid-distance migrators, or resident fish, as determined from the literature and were also grouped by families (ISAAC and BARTHEM, 1995).

For the size-spectrum approach, the natural logarithm of the abundance of fish species by length classes was plotted for all species per year (100 mm length classes with size range 130mm - 2130 mm). We performed linear regressions for 1996, 2001, 2004, 2009, and 2010 and compared values of the parameters b (slope) and a (intercept) and their standard errors (Sb and Sa) using an ANCOVA (R CORE TEAM, 2011). Data were insufficient to test this relationship in other years.

RESULTS

During the period evaluated, the minimum yield was 353 tons (1990), and the maximum was 1589 tons in 2008 (Figure 2). The average annual yield was 566.5 tons (± 193.6), with a significant temporal variation of the catch between the years (Kruskal-Wallis H=59.912; df=19; P<0.001). The yearly variation was not correlated with the water level of the river (r= 0.17; p=0.22), even when capture was compared to the level of the previous year (r = 0.134; p=0.31) or the previous two years (r= - 0.15; p=0.27).

The fishery was very diverse: we identified 60 fish species in the landings, but some groups are more representative (Table 1, a complete list of landed species is shown in DORIA *et al*., 2012). In some cases, the local fishermen referred to different species by the same common name (*e.g.*, the Serrasalmidae in the genera *Myleus* spp. and *Mylossoma* spp. are both called "pacu" and the Curimatidae *Psectrogaster amazonica, Potamorhina altamazonica,* and *Potamorhina latior* are all called "branquinha"). This fact hindered the separation of yield values by species.

Landings were dominated by 19 species that comprised approximately 80% of the catch, with variation during the study years, and a slight prevalence of *Myleus* spp., *Mylossoma* spp, *Brachyplatystoma rousseauxii,* and *Prochilodus nigricans* (Table 1). The high yield observed in 1993 was dominated by four species (*Prochilodus nigricans, Semaprochilodus taeniurus*, and *Semaprochilodus insignis*), while in 1997 *Brycon amazonicus* was the dominant species, and in 2001 and 2005 *Prochilodus nigricans*; *Myleus* spp. and *Mylossoma* spp. were dominant (Figure 2; Table 1).

Characiformes were predominant (50 to 65% of landings), and Siluriformes represented around 14 to 22% of the yield/year. Most of the Characiformes were medium size while Siluriformes were of medium and large sizes. Mid-distance migratory species dominated the catch (Table 1). The number of fishermen and

Table 1. Relative capture (yields represents >2% of the total landings, for at least one year) landed in Porto Velho, at 5-year intervals (excluding 2008), with average length (cm), main trophic category, migratory habits (Migr.), and trophic level (TL - estimated by stomach content analysis).

Order/Family	Scientific name	Yield (%)				Mean length	Trophic category	Migr.	TL	Stomachs (n)
Characiformes		90-94	95-99	00-04	05-10					
Anostomidae	*Schizodon fasciatum* Spix and Agassiz, 1829	0.63	1.16	0.63	**4.79**	24.4	Herbivorous	MD	2	16
Characidae	*Brycon amazonicus* (Spix and Agassiz, 1829)	9.90	**13.73**	9.90	7.23	38.2	Omnivorous	MD	2	46
	Triportheus sp.	2.81	**6.59**	2.81	3.98	20.1	Omnivorous	MD	2.7	222
Serrasalmidae	*Myleus* spp.*; Mylossoma* spp.	10.49	**12.30**	10.49	10.67	19.2	Frugivorous	MD	2	81
	Colossoma macropomum (Cuvier, 1816)	2.39	2.07	2.39	1.01	53.0	Frugivorous	MD	2	8
Curimatidae	*Psectrogaster amazonica* Eigenmann and Eigenmann, 1889*; Potamorhina altamazonica* (Cope, 1878); *P. latior* (Spix and Agassiz, 1829)	6.67	2.33	**6.67**	3.00	20.5	Detritivorus	MD	2	497
Prochilodontidae	*Prochilodus nigricans* Spix and Agassiz, 1829	**19.46**	14.08	**19.46**	12.96	28.9	Detritivorus	MD	2.3	61
	Semaprochilodus taeniurus (Valenciennes, 1821)*; S. insignis* (Jardine, 1841)	12.58	8.78	12.58	6.35	21.5	Detritivorus	MD	2	
Siluriformes										
Pimelodidae	*Brachyplatystoma rousseauxii* (Castelnau, 1855)	10.32	**18.60**	10.32	8.75	81.3	Carnivorous	LD	3.2	170
	B. filamentosum (Lichtenstein, 1819)	1.36	1.18	1.36	2.15	86.1	Carnivorous	LD	3.5	111
	Pinirampus pirinampu (Spix and Agassiz, 1829)	0.59	0.01	0.59	3.21	39.4	Carnivorous	MD	3	15
	Pseudoplatystoma spp.	1.32	1.87	1.32	**4.80**	51.6	Carnivorous	MD	2.6	35
Perciformes										
Cichlidae	*Cichla* sp.	1.14	1.02	1.14	3.95	3.0	Carnivorous	R	2.6	8
	Other species	20.34	16.29	20.34	27.15				NI	1232
	Total yield (tons)	2.65	2.93	2.65	2.87					

LD = Long distance; MD = Mid-distance; R = Residents and NI = Not Identified; bold numbers indicate the highest percentage catch by year.

boats that landed in the Porto Velho fish market declined during the years (Table 2).

The mean trophic level (TL) of the catch exhibited slight variations through the study period (2.44 ± 0.1; Figure 3a) with an increasing trend towards the end. This increase may be due to a reduction of the yield of lower TL species in the last seven years (Figure 3b) and an increase in carnivorous fish yield (*Pseudoplatystoma* spp., *Pininampus pirinampu* and *Brachyplatystoma filamentosum*). Overall, the dominant feeding behavior was detritivorous (TL between 2.00 and 2.39).

Notwithstanding this yearly variation, FiB index dynamics showed a slight overall increase from 1990 to 2008 (Figure 4a), reflecting a minimal increase in the catch of TL highest species (Figure 4b). The L index also exhibited many oscillations, but the low values seem to indicate the fisheries are sustainable (Figure 4b).

The structure of the fish communities, measured as the slope from size spectrum analysis of size distribution, varied between 1996 and 2010 (Figure 5 and Table 2). However, the variation in the number of individuals sampled may have influenced the results of this analysis (Table 3).

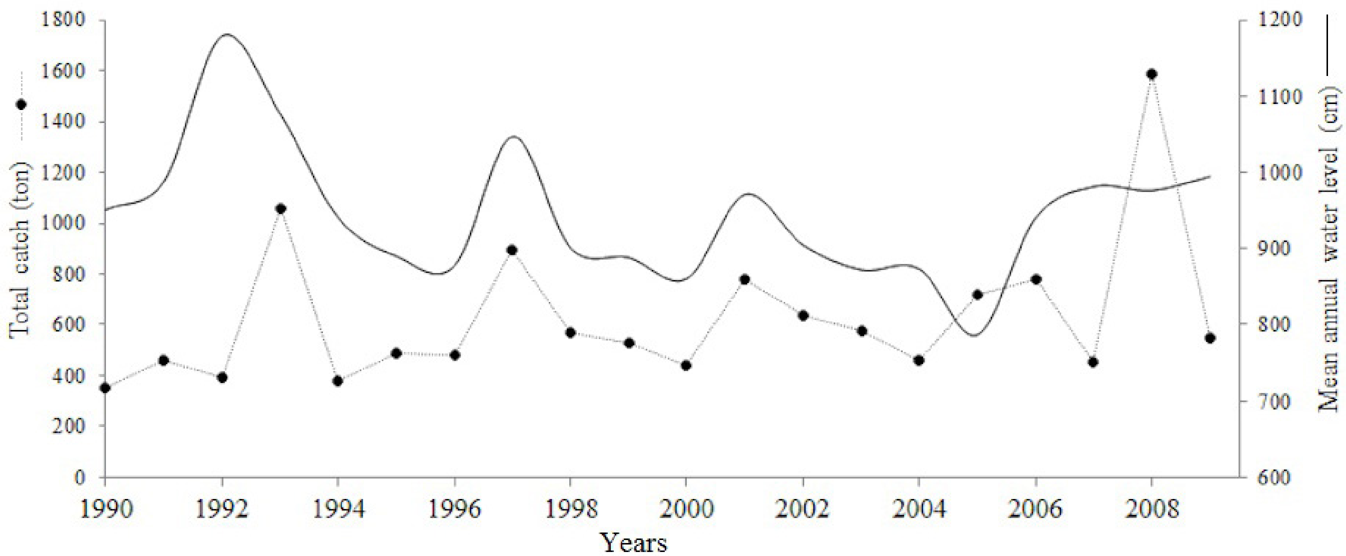

Figure 2. Annual catch (ton) landed in the Cai N'água fishing market in Porto Velho (Amazon - Brazil; Source: Porto Velho Fishermen's Colony) and the average annual water level – WL (cm); (Source: Porto Velho station - Mineral Resources Research Company).

Table 2. Number of fishermen and boats that landed per year in the Cai N'água fishing market in Madeira River (Porto Velho, Brazil - Source: Fishermen's colony, Tenente Santana, Z-1).

Number of	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2006	2007
Fishermen	235	264	206	229	214	184	171	129	162	158	186	197
Fishermen Boats	27	26	26	27	27	23	22	22	21	21	7	6

Table 3. Size-spectra analysis. Parameters values of relationship between the (ln) number of individuals and length classes (by year; see Figure 5) in Cai N'água fishing market Porto Velho (Rondônia - Brazil).

Year	b	Sb	a	Sa	R^2	Class Number	N
1996	-0.0028*	0.0005	4.967	0.814	0.584	30	2342
2001	-0.0052	0.0012	6.985	0.843	0.681	11	2050
2004	-0.0055	0.0012	7.691	0.821	0.713	11	3396
2009	-0.0048	0.0004	9.239	0.544	0.884	25	17919
2010	-0.0041*	0.0004	8.523	0.494	0.862	23	15438

b: Slope; a: intercept (a) with corresponding standard errors (Sa and Sb); *indicated deference between the years ($p<0.005$).

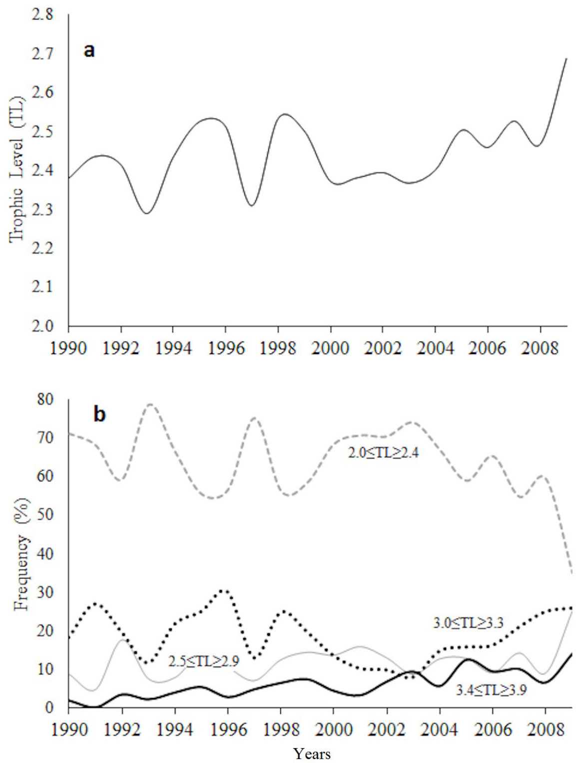

Figure 3. Annual average of the Trophic level (TL) of the catch (a) and the frequency (%) of tons for each trophic level (TL) category ranging from detritivorous to carnivorous: 2.0 to 2.49; 2.5 to 2.99; 3.0 to 3.39; 3.4 to 4.0 (b) of the all species landed on the Cai N'água market, Porto Velho City (Rondônia, Brazil; Source: Fishermen's colony Z1).

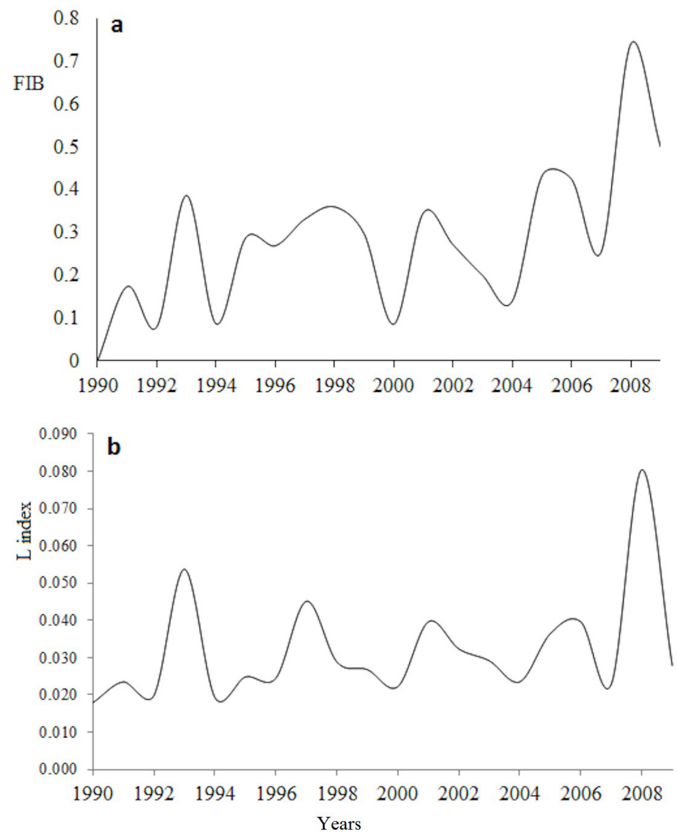

Figure 4. (a) FiB (Fishing in Balance Index) and (b) L-index (Loss of Secondary Production Index). All measurements are for the species landed on the Cai N'água market, Porto Velho (Amazon Brazil). See formulas in main text.

DISCUSSION

Status of Madeira River fish community

The fisheries landings in the region of Porto Velho during 1990-2009, using the ecosystem approach, seem to be stable, although between-years variation was high. This stable dynamic was seen for all indices estimated: mean trophic level, frequency of TL, fishing in balance, and L-index, with all of them having yearly oscillations without any apparent trends. However, size-spectra analysis showed an increase in catch of larger individuals in more recent years.

The decrease in the number of fisher and boats that landed in the Porto Velho market demonstrates changes in the commercial relationship in the region. In the 90's fishing boats, in addition to fishing, also bought the fish in the riverside communities along the Madeira River. In 2000's, was implemented the Rondônia Fishing Law (Lei nº. 1038 de 2002; RONDÔNIA, 2002) which increased the inspection on fishing boats, which probably led to a decrease in the number of boats. At his time, the riverine fishers begin to send their fish on the "barco recreio" (large boats that carry people and goods along the Madeira River), directly to the middlemen located in the Porto Velho fish market (C. Doria, personal observation), who records this fish in its own name. This also explains the decrease in the number of registered fishermen over the years. Unfortunately, the number of fishermen and boats are insufficient to be considered a trustily proxy of fishing effort, and we avoided to find a relation between these two variables to other indexes.

Substantial annual variation in landings is typical for the Amazon region, and is often related to water level (PETRERE JUNIOR, 1978; MERONA, 1993). Although we did not observe a positive relationship between higher total catch and larger floods, as did BATISTA *et al*. (2012) or negative relation with drought as did FABRÉ *et al*. (2017). However, LIMA *et al*. (2017) studying the ten most important commercial species at the Porto Velho market and the same period of our study, observed that the maximum water level, days flooded, river flow of previous year were a drive in the catch increasing of these species.

Despite the apparent stability of the total yield, the catch of individual species varied. Species contribution to the total yield changed over time, though the dominant orders and families did not. It was not observed in the TL dynamic, that showed a small change in TL and feeding categories, since related species

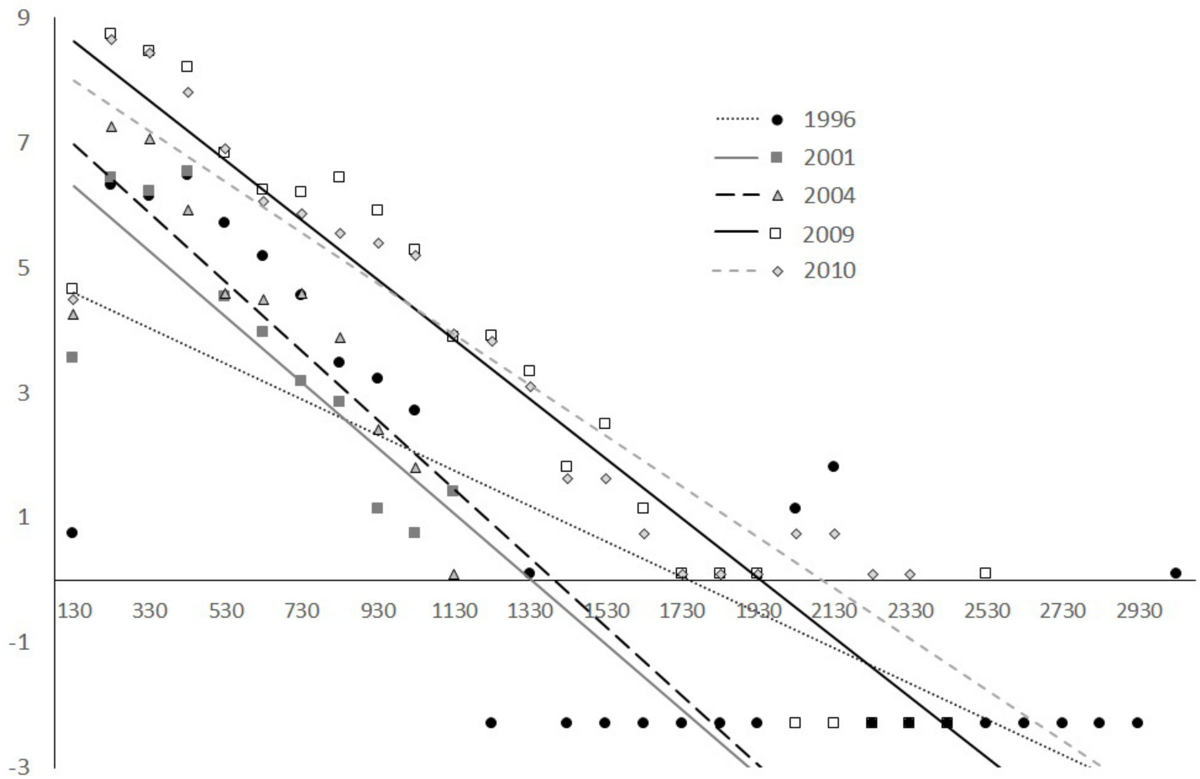

Figure 5. Structure of the fish communities, measured as the slope from "size-spectra" analysis, and corresponding linear regressions (see Table 2). Measurements are for all the species landed on the Cai N'água market (see Table 1), Porto Velho (Amazon, Brazil) between 1990 and 2010.

have the same TL, and was in the same group. However, it is worth noting a small increase in TL in the last five years of our study. Despite reductions in the total yield, there was a slight and gradual increase in capture of species in medium and high trophic levels (TL> 3.0) and a strong decrease in capture of species in lower trophic level (TL< 2.3). Thus, the fishing pressure seems to be diluted in the different trophic levels even when there is a replacement of species in landing composition within the trophic category. Again, it is likely that this is possible due to the multispecies fisheries in the Amazon region.

The increase in FiB index, especially in the last years of the study, corresponds to a period of fisheries expansion, increasing the relative contribution of *Pseudoplatystoma* spp., *Pinirampus pirinampu,* and *Brachyplatystoma filamentosum*. A caveat is that in 2008 there was a marked increase in "pacu" (*Myleus* spp.; *Mylossoma duriventre*). Despite an increase in FiB, which could indicate sustainable fishing, the total yield decreased in 2010. According to PAULY *et al*. (2000), FiB<0 reflects a system that is functioning less efficiently than it should due to intensive fishing pressure. The opposite value was observed in the fisheries of the Porto Velho market, suggesting that the fishing pressure on the Madeira is relatively small and therefore sustainable.

Also, the L index values (0.02 – 0.04), suggest sustainability of exploitation of around 75% (see LIBRALATO *et al*., 2008 for details). A simulation of the L index in other major Brazilian floodplains revealed sustainability of exploitation values that were even greater (ANGELINI *et al*., 2013), showing that the inherent dynamics in this type of environment can contribute to the fishery sustainability. One of the oldest indicators of fishing pressure is a reduction in mean length of the landed species (SMITH, 1994). When fishing intensity increases, the slope and intercept of the size spectra should increase proportionally to fishing effort (GISLASON and RICE, 1998; FABRÉ *et al*., 2017). Such increase in intercept was observed for our data, in the most recent years evaluated (2009, 2010), when there were more individuals in the bigger size class, meaning that there has not been heavy pressure on the fish stocks over the last 20 years. These results suggest that a change in fishing strategies, increased the catch of Siluriformes, which represents an increment in biomass on species more profitable.

Amazonian fisheries are dominated by migratory Characiformes, species of small-to-medium length (Lmax between 20 to 40 cm) with high capacity to replenish stocks as well as a lower rate of change in slope of the size spectra due to fishing pressure (ISAAC *et al*., 2012). In some areas of South America, the species composition, abundance, and ecology of the fish communities have not been altered by fishing pressure and catches still include large species, meaning there is likely some potential to increase the catch (WELCOMME *et al*., 2010). One of the great current challenges in the Amazon is to reconcile conservation of its natural resources with sustainable development of the region. The addition of large energy plants is a great threat to the maintenance of fishing in the region. In the Madeira basin, two large dams were built in 2011 and 2012. Our data show that the fishing was stable before dam construction, but the dams could threaten this stability (AGOSTINHO *et al*., 2008). Changes resulted hydropower development will affect water quantity, quality, and timing that create substantial and irreversible social and ecological impacts (FEARNSIDE, 2013). Amazonian fish species are highly dependent on variations in rainfall and water flow for growth and reproduction, making them vulnerable to local hydrological alterations caused by such large-scale development projects (WINEMILLER *et al*., 2016).

Performance of the use combined indicators

Measuring fishery status or ecosystem changes is not straightforward, and a single indicator is generally inadequate to monitor the complexity of changes observed, although the use of multiple indicators can be effective (BLANCHARD *et al*., 2010). For the Madeira River, our use of multiple indicators helped to clarify that, despite catch diminishing in the last year, both trophic level and size of species have increased, likely reflecting the fishermen's preference for more valued species (Siluriformes families). Thus, we conclude that it can be informative to monitor fisheries in tropical freshwater ecosystems by estimating the trophic level and the size spectra indicators despite their high diversity of species (as suggested by FABRÉ *et al*., 2017). Although these indicators necessarily have more uncertainty than would high quality and continuous landing data such as would be acquired in full-scale stock assessments, which remain needed in the Amazon.

Moreover, the Madeira River landings showed some oscillations (Figure 2) which were transformed into drastic oscillations by FiB and L index indicators (Figure 4). In marine and industrial fisheries, oscillations are smaller, and trends are clear (SHANNON *et al*., 2009) reflecting more organization of fisheries fleets and in some cases a lack of extreme events due to environmental conditions. By contrast, in a small-scale fishery like the one examined here, a single specific shoal can change all annual landing and water level oscillations trends to influence habitats and fishermen's behavior.

CONCLUSION

We recognize that these data-limited methods are constrained regarding their utility to drive sophisticated stock assessments. However, data are often lacking about fisheries in developing countries (CARRUTHERS *et al*., 2014); in these cases, using a single indicator without understanding the dynamics of fisheries or analyzing the causes of observed trends would be insufficient (CURY *et al*., 2005). Our work here shows that a combination of multiple, relatively easy-to-collect indicators provides valuable information about data-limited fisheries.

ACKNOWLEDGEMENTS

We thank the Fishermen's Colony for long-term monitoring; the Pró-Amazônia/Capes (Project No: 3326/2013) for the support and also the Graduate Program in Regional Development and Environment at Universidade Federal de Rondônia for scholarship (Capes) of A. Lima.

REFERENCES

AGOSTINHO, A.A.; PELICICE, F.M.; GOMES, L.C. 2008 Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, *68*(4, suppl.): 1119-1132. **http://dx.doi.org/10.1590/S1519-69842008000500019**. PMid:19197482.

ANGELINI, R.; FABRÉ, N.N.;SILVA JUNIOR, U.L. 2006 Trophic analysis and fishing simulation of the biggest Amazonian catfish. *African Journal of Agricultural Research*, *1*: 151-158.

ANGELINI, R.; MORAIS, R.J.; CATELLA, A.C.; RESENDE, E.K.; LIBRALATO, S. 2013 Aquatic food webs of the oxbow lakes in the Pantanal: a new site for fisheries guaranteed by alternated control? *Ecological Modelling*, *253*(1): 82-96. **http://dx.doi.org/10.1016/j.ecolmodel.2013.01.001**.

APEL, A.M.; FUJITA, R.; KARR, K. 2013 *Science-based management of data-limited fisheries: a supplement to the catch share design manual*. New York: Environmental Defense Fund. 27p.

BATISTA, V.S.; ISAAC, V.J.; FABRÉ, N.N.; GONZALEZ, J.C.A. 2012 Principais recursos pesqueiros: variações espaço- temporais e relações com o ambiente. In: BATISTA, V.S.; ISAAC, V.J. *Peixes e pesca no Solimões-Amazonas: uma avaliação integrada*. Brasília: IBAMA/MMA. p. 135-170.

BLANCHARD, J.; DULVY, N.; JENNINGS, S.; ELLIS, J.; PINNEGAR, J.; TIDD, A.; KELL, L. 2005 Do climate and fishing influence size-based indicators of Celtic Sea fish community structure? *ICES Journal of Marine Science*, *62*(3): 405-411. **http://dx.doi.org/10.1016/j.icesjms.2005.01.006**.

BLANCHARD, J.L.; COLL, M.; TRENKEL, V.M.; VERGNON, R.; YEMANE, D.; JOUFFRE, D.; LINK, J.S.; SHIN, Y.J. 2010 Trend analysis of indicators: a comparison of recent changes in the status of marine ecosystems around the world. *ICES Journal of Marine Science*, *67*(4): 732-744. **http://dx.doi.org/10.1093/icesjms/fsp282**.

CARRUTHERS, T.R.; PUNT, A.E.; WALTERS, C.J.; MACCALL, A.; MCALLISTER, M.K.; DICK, E.J.; COPE, J. 2014 Evaluating methods for setting catch limits in data-limited fisheries. *Fisheries Research*, *153*(1): 48-68. **http://dx.doi.org/10.1016/j.fishres.2013.12.014**.

CELLA-RIBEIRO, A.; LIMA-FILHO, J.A.; RÖPKE, C.P.; HAUSER, M.; SILVA, T.M.; FONSECA, M.L.; TORRENTE-VILARA, G. 2016 Catálogo de informações biológicas de peixes do rio Madeira. In: CELLA-RIBEIRO, A.; TORRENTE-VILARA, G.; LIMA-FILHO, J.A.; DORIA, C.R.C. *Ecologia e biologia de peixes do rio Madeira*. Porto Velho: Edufro. p. 56-78.

CHRISTENSEN, V. 2015 Fishing down through the food web. *Fisheries*, *40*(8): 370-372. **http://dx.doi.org/10.1080/03632415.2015.1065155**.

CURY, P.; SHANNON, L.; ROUX, J.; DASKALOV, G.; JARRE, A.; MOLONEY, C.; PAULY, D. 2005 Trophodynamic indicators for an ecosystem approach to fisheries. *ICES Journal of Marine Science*, *62*(3): 430-442. **http://dx.doi.org/10.1016/j.icesjms.2004.12.006**.

DORIA, C.R.C.; LIMA, M.A.L. 2015 *Rio Madeira: seus peixes e sua pesca*. Porto Velho: Edufro e Rima Editora.

DORIA, C.R.C.; RUFFINO, M.L.; HIJAZI, N.C.; CRUZ, R.L. 2012 A pesca comercial na bacia do rio Madeira no estado de Rondônia, Amazônia brasileira. *Acta Amazonica*, *42*(1): 29-40. **http://dx.doi.org/10.1590/S0044-59672012000100004**.

ESCOBAR, H. 2015 Brazil roils waters with moves to protect aquatic life. *Science*, *348*(6231): 169. **http://dx.doi.org/10.1126/science.348.6231.169**. PMid:25859024.

FABRÉ, N.; CASTELLO, L.; ISAAC, V.J.; BATISTA, V.S. 2017 Fishing and drought effects on fish assemblages of the Central Amazon Basin. *Fisheries Research*, *188*(1): 157-165. **http://dx.doi.org/10.1016/j.fishres.2016.12.015**.

FEARNSIDE, P.M. 2013 Viewpoint-decision making on amazon dams: politics trumps uncertainty in the madeira river sediments controversy. *Water Alternatives*, *6*(2): 313-325.

GISLASON, H.; RICE, J. 1998 Modelling the response of size and diversity spectra of fish assemblages to changes in exploitation. *ICES Journal of Marine Science*, *55*(3): 362-370. **http://dx.doi.org/10.1006/jmsc.1997.0323**.

GOULDING, M. 1979 *Ecologia da pesca do rio Madeira*. Manaus: INPA. 172p.

GRANTHAM, R.W.; RUDD, M.A. 2015 Current status and future needs of economics research of inland fisheries. *Fisheries Management and Ecology*, *22*(6): 458-471. **http://dx.doi.org/10.1111/fme.12144**.

INOMATA, S.O.; FREITAS, C.E.C. 2015 A pesca comercial no médio rio negro: aspectos econômicos e estrutura operacional. *Boletim do Instituto de Pesca*, *41*(1): 79-87.

ISAAC, V.J.; BARTHEM, R.B. 1995 Os recursos pesqueiros da Amazônia brasileira. *Boletim do Museu Paraense Emílio Goeldi, Série Antropologia*, *11*(2): 295-339.

ISAAC, V.J.; FABRÉ, N.N.; SILVA, C.O.; RUFINO, M.L.; SAINT-PAUL, U. 2012 Ecologia da fauna ictíica. In: BATISTA, V.S.; ISAAC, V.J. *Peixes e pesca no Solimões-Amazonas: uma avaliação integrada*. Brasília: IBAMA/MMA. p. 207-249.

LIBRALATO, S.; COLL, M.; TUDELA, S.; PALOMERA, I.; PRANOVI, F. 2008 Novel index for quantification of ecosystem effects of fishing as removal of secondary production. *Marine Ecology Progress Series*, *355*(1): 107-129. **http://dx.doi.org/10.3354/meps07224**.

LIMA, M.A.L. 2017 *História do ecossistema e dos recursos pesqueiros frente a implementação de hidrelétricas na bacia do rio Madeira*. Porto Velho. 138f. (Tese de Doutorado. Universidade Federal de Rondônia). Available from: <http://www.pgdra.unir.br/downloads/6709_maria_alice_lima_tese_2013_2017.pdf>. Access on: 12 apr. 2017.

LIMA, M.A.L.; DORIA, C.R.C.; FREITAS, C.E.C. 2012 Pescarias artesanais em comunidades ribeirinhas na Amazônia brasileira: perfil socioeconômico, conflitos e cenário da atividade. *Ambiente & Sociedade*, *15*(2): 73-90. **http://dx.doi.org/10.1590/S1414-753X2012000200005**.

LIMA, M.A.L.; KAPLAN, D.A.; DORIA, C.R.C. 2017 Hydrological controls of fisheries production in a major Amazonian tributary. *Ecohydrology*, *10*(8): e1899. **http://dx.doi.org/10.1002/eco.1899**.

MERONA, B. 1993 Pesca e ecologia dos recursos aquáticos na Amazônia. In: FURTADO, L.G.; MELLO, A.F.; LEITÃO, W. *Povos das águas: realidades e perspectivas na Amazônia*. Belém: Museu Paraense Emílio Goeldi. p. 159-185.

PAULY, D.; CHRISTENSEN, V. 1995 Primary production required to sustain global fisheries. *Nature*, *374*(6519): 255-257. **http://dx.doi.org/10.1038/374255a0**.

PAULY, D.; CHRISTENSEN, V.; DALSGAARD, J.; FROESE, R.; TORRES JUNIOR, F. 1998 Fishing down marine food webs. *Science*, *279*(5352): 860-863. **http://dx.doi.org/10.1126/science.279.5352.860**. PMid:9452385.

PAULY, D.; CHISTENSEN, V.; WALTERS, C. 2000 Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science*, *57*(3): 697-706. **http://dx.doi.org/10.1006/jmsc.2000.0726**.

PETRERE JUNIOR, M. 1978 Pesca e esforço de pesca no Estado do Amazonas. II. Locais, aparelhos de captura e estatísticas de desembarque. *Acta Amazonica*, *8*(2): 4-54.

QUEIROZ, L.J.; TORRENTE-VILARA, G.; OHARA, W.; PIRES, T.H.S.; ZUANON, J.; DORIA, C.R.C. 2013 *Peixes do Madeira*. São Paulo: Dialeto. v. 1-3.

R CORE TEAM. 2011 *R: a language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Available from: <http://www.R-project.org>. Access on: 12 apr. 2014.

RICE, J.; GISLASON, H. 1996 Patterns of change in the size spectra of numbers and diversity of the North Sea fish assemblage, as reflected in surveys and models. *ICES Journal of Marine Science*, *53*(6): 1214-1225. **http://dx.doi.org/10.1006/jmsc.1996.0146**.

RONDÔNIA, 2002 LEI nº 1038, de 22 de janeiro de 2002. Estabelece diretrizes para proteção à pesca e estímulos à aquicultura do Estado de Rondônia e dá outras providências. *Diário Oficial*, Rondônia, 22 de janeiro de 2002.

RUFFINO, M.L. 2014 Status and trends of the fishery resources of the Amazon Basin in Brazil. In: WELCOMME, R.L.; JORGENSEN, J.; HALLS A.S. *Inland fisheries evolution and management: case studies from four continents*. Rome: FAO. p. 1-20.

SANTOS, M.A.; SANTOS, M.F.; BRANCO, J.O.; BARBIERI, E. 2016 Caracterização da pesca e dos pescadores artesanais de camarões penaeidae em salina no município de Macau - Rio Grande do Norte. *Boletim do Instituto de Pesca*, *44*(2): 465-478. **http://dx.doi.org/10.20950/1678-2305.2016v42n2p465**.

SHANNON, L.J.; COLL, M.; NEIRA, S. 2009 Exploring the dynamics of ecological indicators using food web models fitted to time series of abundance and catch data. *Ecological Indicators*, *9*(6): 1078-1095. **http://dx.doi.org/10.1016/j.ecolind.2008.12.007**.

SMITH, T.D. 1994. *Scaling fisheries: the science of measuring the effects of fishing, 1855-1955*. Cambridge: Cambridge University Press. 392p. **http://dx.doi.org/10.1017/CBO9780511470868**.

WELCOMME, R.L.; COWX, I.G.; COATES, D.; BENE, C.; FUNGE-SMITH, S.; HALLS, A.; LORENZEN, K. 2010 Inland capture fisheries. *Philosophical Transactions of the Royal Society of London*.

Series B, Biological Sciences, *365*(1554): 2881-2896. **http://dx.doi.org/10.1098/rstb.2010.0168**. PMid:20713391.

WELCOMME, R.L.; JORGENSEN, J.; HALLS, A.S. 2014 *Inland fisheries evolution and management: case studies from four continents*. Rome: FAO. Available from: <http://www.fao.org/3/contents>. Access on: 12 apr. 2014.

WINEMILLER, K.O.; MCINTYRE, P.B.; CASTELLO, L.; FLUET-CHOUINARD, E.; GIARRIZZO, T.; NAM, S.; BAIRD, I.G.; DARWALL, W.; LUJAN, N.K.; HARRISON, I.; STIASSNY, M.L.; SILVANO, R.A.; FITZGERALD, D.B.; PELICICE, F.M.; AGOSTINHO, A.A.; GOMES, L.C.; ALBERT, J.S.; BARAN, E.; PETRERE JUNIOR, M.; ZARFL, C.; MULLIGAN, M.; SULLIVAN, J.P.; ARANTES, C.C.; SOUSA, L.M.; KONING, A.A.; HOEINGHAUS, D.J.; SABAJ, M.; LUNDBERG, J.G.; ARMBRUSTER, J.; THIEME, M.L.; PETRY, P.; ZUANON, J.; TORRENTE VILARA, G.; SNOEKS, J.; OU, C.; RAINBOTH, W.; PAVANELLI, C.S.; AKAMA, A.; VAN SOESBERGEN, A.; SÁENZ, L. 2016 Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science*, *351*(6269): 128-129. **http://dx.doi.org/10.1126/science.aac7082**. PMid:26744397.