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Fishers' knowledge identifies environmental changes and fish abundance trends in impounded tropical rivers

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Abstract. The long-term impacts of large hydroelectric dams on small-scale fisheries in tropical rivers are poorly known. A promising way to investigate such impacts is to compare and integrate the local ecological knowledge (LEK) of resource users with biological data for the same region. We analyzed the accuracy of fishers' LEK to investigate fisheries dynamics and environmental changes in the Lower Tocantins River (Brazilian Amazon) downstream from a large dam. We estimated fishers' LEK through interviews with 300 fishers in nine villages and collected data on 601 fish landings in five of these villages, 22 years after the dam's establishment (2006–2008). We compared these two databases with each other and with data on fish landings from before the dam's establishment (1981) gathered from the literature. The data obtained based on the fishers' LEK (interviews) and from fisheries agreed regarding the primary fish species caught, the most commonly used type of fishing gear (gill nets) and even the most often used gill net mesh sizes but disagreed regarding seasonal fish abundance. According to the interviewed fishers, the primary environmental changes that occurred after the impoundment were an overall decrease in fish abundance, an increase in the abundance of some fish species and, possibly, the local extinction of a commercial fish species (*Semaprochilodus brama*). These changes were corroborated by comparing fish landings sampled before and 22 years after the impoundment, which indicated changes in the composition of fish landings and a decrease in the total annual fish production. Our results reinforce the hypothesis that large dams may adversely affect small-scale fisheries downstream and establish a feasible approach for applying fishers' LEK to fisheries management, especially in regions with a low research capacity.

Key words: Brazilian Amazon; fisheries management; freshwater fish; human ecology; hydroelectric dams; impact assessment; interviews; small-scale fisheries; Tocantins River.

Introduction

Human populations have detailed local ecological knowledge (LEK) about the spatial distribution, biology (reproduction, diet), migratory behavior, temporal trends in abundance, extinction risk, vulnerability to exploitation, and ecological interactions of species that serve as natural resources (Huntington 2000, Huntington et al. 2004, Saenz-Arroyo et al. 2005, Silvano et al. 2006, 2008, Jones et al. 2008, Lavides et al. 2010). Researchers working in the fields of applied ecology and resource management have increasingly used LEK to fill gaps in scientific knowledge, to devise new testable scientific hypotheses and to propose participative management measures (Johannes et al. 2000, White et al. 2005, Brook and McLachlan 2008, Rochet et al. 2008, Silvano and Valbo-Jorgensen 2008, Irvine et al. 2009). In addition to its application in improving knowledge about specific organisms, the LEK of resource users can also be helpful for evaluating broader environmental changes over temporal scales ranging from years to decades. For example, LEK has been useful for evaluating the temporal patterns of fish abundance and associated ecosystem processes in the North Atlantic (Rochet et al. 2008), changes in the vegetation composition and productivity of grazing fields (Fernandez-Gimenez 2000), fish kills linked to the hydrological cycle in a tropical wetland (Calheiros et al. 2000), the hydrodynamics of an alpine lake (Laborde et al. 2012) and the long-term impacts of changes in climatic conditions and ice cover for Arctic animals (Huntington 2011). However, although the potential of LEK is currently recognized, few studies have compared LEK and biological data from the same region and at the same spatial scale (Aswani and Hamilton 2004, Salomon et al. 2007, Jones et al. 2008, Rochet et al. 2008, Silvano and Begossi 2010, Daw et al. 2011), few of these comparative surveys have been conducted in freshwater ecosystems (Silvano et al. 2008). Such comparisons are important for enhancing the dialogue

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between scientists and LEK holders, overcoming the obstacles and prejudices of conventional scientists toward LEK, and properly addressing the contributions and limitations of LEK (Daw et al. 2011, Huntington 2011).

LEK should not be uncritically accepted, and its limitations should be carefully analyzed through well-designed research (Davis and Ruddle 2010). Among the limitations of LEK is the fact that it relies on people's perceptions, which may be influenced by the cultural context or political opinions (Maurstad et al. 2007). Resource users, such as fishers, can better perceive and comment on decreases in resource abundance compared with increases (Daw et al. 2011); fishers may also explain changes primarily in terms of environmental factors, instead of acknowledging the consequences of their own activities (Rochet et al. 2008). Hence, the cultural context should be considered to avoid incorrect interpretation of LEK, and the participants interviewed and included in LEK surveys should be carefully selected (Davis and Wagner 2003, Davis and Ruddle 2010). Another limitation of fishers' LEK as an indicator of temporal environmental changes is the shifting baseline syndrome: younger people may have an inaccurate or biased perception of past changes, due to generational amnesia (communication failure between generations) or personal amnesia (people forget past conditions; Papworth et al. 2009). Furthermore, fishers' LEK does not always agree with biological surveys (Aswani and Hamilton 2004, Silvano and Begossi 2010, Daw et al. 2011), and fishers have been shown to possess limited knowledge on certain topics in some cases, such as regarding the spawning seasons and habitats of some fishes (Silvano et al. 2006). Nevertheless, recent surveys based on structured and systematic research have demonstrated that fishers' LEK may be highly compatible with biological, fisheries, and even physical data (Silvano and Begossi 2005, Le Fur et al. 2011, Zukowski et al. 2011, Laborde et al. 2012), therefore representing a useful, but often neglected, data source for fisheries management. Indeed, in some situations, fishers' LEK may be a unique available source of data, such as regarding fish migrations in large rivers (Valbo-Jorgensen and Poulsen 2000) or along the coast (Silvano et al. 2006), fish nursery sites (Le Fur et al. 2011), and past abundance trends of exploited fish and invertebrates (Saenz-Arroyo et al. 2005, Salomon et al. 2007, Lavides et al. 2010).

Fishers' LEK has rarely been applied to understand the impacts and changes related to river impoundment. The impoundment of rivers to produce hydroelectric energy may cause environmental, social, and economic impacts (Petrere 1996, Fearnside 1999), including changes in the fish composition, reproductive delays, reductions in size, and shortages in the abundance of fishes downstream from the dam (de Mérona 1990, Zhong and Power 1996, Ponton and Vauchel 1998, Gehrke et al. 2002). Hydroelectric plants in tropical rivers may release oxygen and nutrient-poor water downstream because of nutrient and sediment retention in reservoirs, which reduce water quality (Petrere 1996, de Mérona et al. 2001, 2010). Changes in the water level and artificial control of water flows and of the flooding pulse due to reservoir operation can also affect fish feeding and spawning (Zhong and Power 1996, Ponton and Vauchel 1998, Agostinho et al. 2004). However, studies addressing such impacts in tropical and subtropical rivers have usually been restricted in time and place: only a few have included samples from both before and after an impoundment (Ponton and Vauchel 1998, de Mérona and Albert 1999, de Mérona et al. 2001, Penczak et al. 2009). Although a number of large dams have been built and more are being planned for the large rivers in the Brazilian Amazon (Fearnside 1999), few studies have addressed the potential ecological consequences of such dams for fish and local fishers (Silvano et al. 2009). Small-scale fisheries are one of the main sources of income and animal protein for poor populations in developing tropical countries, especially in the Brazilian Amazon (Cetra and Petrere 2001, MacCord et al. 2007, Coomes et al. 2010, Hallwass et al. 2011). The lack of long-term ecological data available to inform management and policy, together with the scarcity of both financial and expert resources with which to gather such data, makes the application of fishers' LEK a potentially useful approach to addressing the ecological impacts of dams in large rivers.

We analyzed the potential of fishers' LEK to be used as a complementary and reliable data source about fisheries dynamics and environmental changes in the Lower Tocantins River (Brazilian Amazon) downstream from a large dam. We compared fishers' LEK with fisheries data sampled before (de Mérona et al. 2010) and 22 years after the dam was built. We tested the general hypothesis that large dams alter the fish composition and negatively affect small-scale fisheries downstream (Petrere 1996). A previous survey indicated that there had been a trophic reorganization in the fish communities in the Lower Tocantins River downstream from the dam: carnivorous fish now dominate, while the low concentration of nutrients in the water has reduced the abundance of detritivorous and planktivorous fishes (de Mérona et al. 2001). Additionally, a decrease in fisheries production downstream from the dam was reported soon after the impoundment of the Tocantins River (Ribeiro et al. 1995, Petrere 1996, Fearnside 1999), but this effect has not been quantified. We also tested the hypothesis that the data reported by fishers during interviews accurately reflect current fishing patterns (regarding the gear used and species caught) observed through sampling of fish landings. The long-term ecological effects of dams on fish and fisheries have relevant implications for environmental impact assessment, policy, and management, but such effects have not been addressed with empirical data in large tropical rivers. We therefore provide one of the first comparisons of fishers' LEK and fisheries data in an altered tropical river.

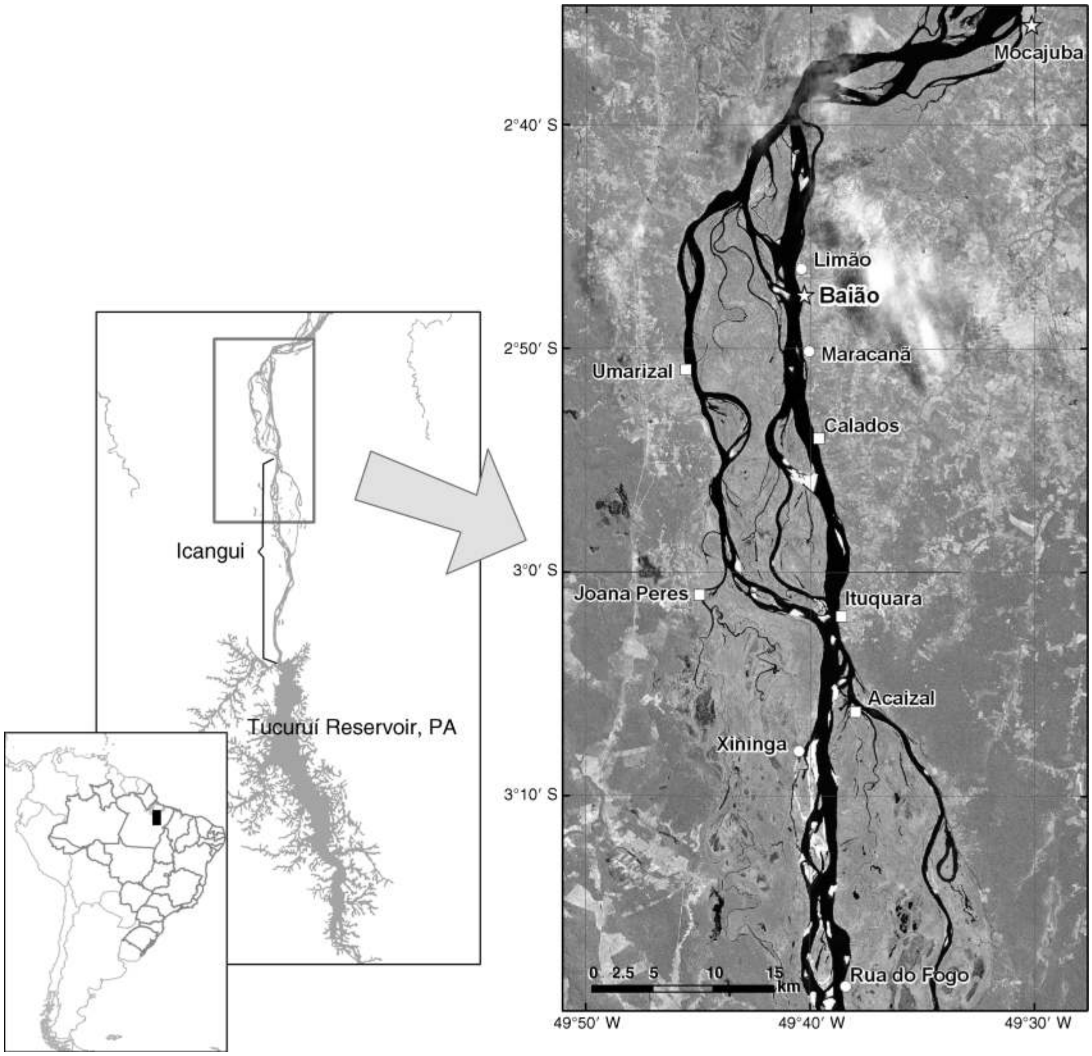

FIG. 1. The studied region in the Lower Tocantins River, Brazilian Amazon, downstream from the Tucuruí reservoir (first inset), illustrating the villages sampled through interviews (circles) and interviews plus fish landings (squares), the cities of Baião and Mocajuba (stars), and the Icangui region sampled by Mérona (1990) (second inset) (modified from Hallwass et al. [2011]).

MATERIALS AND METHODS

Study area

The Tocantins River is a 2750 km long clear-water river in the eastern Brazilian Amazon (Fig. 1), draining an area of 343 000 km^2. Anthropogenic modifications have occurred along this river, such as deforestation and the construction of the Tucuruí dam in 1984, which flooded an area of 2830 km^2 to supply hydroelectric power (Ribeiro et al. 1995, Petrere 1996, Fearnside 1999). The Lower Tocantins River was the most densely inhabited region of the river at the time that the dam was built and is possibly one of the most affected (de Mérona 1990, Ribeiro et al. 1995). The people living in this region and in most of the Amazon are *caboclos* (Portuguese and Indian descendants) who make a living off of small-scale fisheries, agriculture, and cattle husbandry (McGrath et al. 2008; see Plate 1).

Interviews

We interviewed 300 fishers (243 men and 57 women) from nine villages in the Lower Tocantins River approximately 100 km downstream from the Tucuruí dam (Fig. 1) in 2006. The interviews were based on a standardized semi-structured questionnaire addressing fishers' socioeconomic profile as well as their LEK regarding the fisheries and environmental changes in the 22 years following the construction of the Tucuruí dam (Appendix A). This sampling method for recording LEK provided quantitative data (fishers' answers to standardized questions) that were amenable to statistical analyses and revealed the patterns of answers provided by the majority of the interviewees.

When arriving at a fishing village, we first talked to community leaders, who nominated other fishers. The nominated fishers then indicated others according to a snowball sampling procedure, as has been performed in other surveys (Silvano et al. 2006). We first explained the survey's goals, asked for the interviewee's permission, and then interviewed each fisher individually. We ended our sampling in a given village when the fishers being nominated had already been interviewed or when community leaders decided that there would be no other fishers available to interview at that time. This method of sampling did not usually include the whole community, as some fishers were not available to interview at the time of sampling. However, there are 2056 resident families in the studied region (nine villages), and there are 363 fishers associated with the fishing association of the closest city (Baião) (J. A. C. Andrade, unpublished report to Eletronorte), which indicated that our sample pool of 300 fishers was representative for this region.

Fish landings

We recorded 601 fish landings during four hydrological seasons (flooding, high, receding, and low water) in five of the nine sampled villages (Açaizal, n = 94 landings; Calados, n = 119; Ituquara, n = 220; Joana Peres, n = 110; and Umarizal, n = 58; Fig. 1) and 86 fish landings at the public market of Baião city. For logistical reasons, we could sample fish landings in only a subset of the fishing villages where we conducted the interviews, but we considered the subset of villages to be representative of the region. Among the villages that were not sampled for fish landings, Xininga is a small fishing village (approximately five families) close to Açaizal (which was sampled), and Maracanã and Limão are close to the city of Baião, so their fish landings were recorded in the Baião public market. We sampled fish landings from 07:30 to 18:00 at the most often used landing sites (small docks) in each studied village. We interviewed fishers at the landing site about the fishing gear used, the fishing ground visited, and the duration of the fishing trip. We also weighed the fish, which were grouped according to their local names (each representing one or more biological species; Appendix B). Sampling lasted from two to five consecutive days in each village from 2006 to 2008 (67 sampling days). The sampling of fish landings followed the same protocol that was adopted by Eletronorte (the Brazilian company in charge of the Tucuruí dam) to record fish landings at the public market of Baião, the closest city to the studied villages. We used data collected by Eletronorte that were recorded on the same days that we sampled the villages (see Hallwass et al. [2011] for methodological details). Fishing in Baião is practiced by commercial fishers, who are usually not the same fishers living in the villages (Hallwass et al. 2011). Most of the fish landings from the villages lasted less than a day (97%) and were performed with paddled canoes (80%), including two fishers, on average. At the Baião public market, most fish landings lasted more than a day (67%) and were carried out with motor boats (98.8%), also with two fishers on average (Hallwass et al. 2011). We used two measures of fishing productivity: (1) the catch per unit of effort (CPUE), calculated as biomass (kg) per fisher per day, to compare the productivity between months; and (2) the biomass (kg) per fish landing, to compare the productivity recorded before and after the construction of the dam.

Comparison of interviews and fisheries

We performed correlations to compare the answers of the interviewed fishers (n = 300 fishers) regarding the fish species caught and fishing gear used with the data that we recorded from fish landings (n = 601) on the fish caught and gear used. We correlated the number of interviewed fishers who mentioned each fish species (or species group) when answering to the question "What are the main fishes caught?" (item 7, Appendix A) with the biomass of each fish species caught as recorded in the fish landings (item 7, Appendix B). Similarly, we correlated the number of fishers who reported the use of each type of fishing gear when answering to the question "Which fishing gear do you use and in which season do you fish at each site?" (item 8 from Appendix A) with the number of fish landings (frequency) in which each type of fishing gear was used (item 6 from Appendix B). During the interviews, we asked fishers to list only the fish caught and fishing gear used, without mentioning the abundance or frequency of use. We then compared the frequency with which each type of fishing gear was mentioned in the interviews with the actual frequency of use during fishing trips, assuming that gear listed at a high frequency by the interviewees would be equivalent to high use. We followed the same procedure for fish biomass; we compared the frequency with which each fish was mentioned in the interviews with the actual abundance (fish biomass) caught during fishing trips. The biomass of each fish species caught was positively correlated with the number of fishing trips in which each fish species occurred (frequency) ($r = 0.81$, $n = 33$ species, $P < 0.001$). Therefore, the most abundant fish in biomass were also those most commonly caught by fishers, and we chose biomass to measure fish abundance in fishing trips because fishers also use biomass to measure their returns.

In these analyses, we included all of the fishes (fish species groups) mentioned in the interviews and those fishes that corresponded to more than 0.5% of the total biomass in landings (Hallwass et al. 2011). We grouped the interview data from all of the villages for the analyses because our goal was to obtain a broad pattern for the whole region and not to analyze the details of each village. However, the correlations between the number of fishers who mentioned each fish species and the biomass of each fish species caught in fish landings were positive and significant for all individual villages (Appendix C), and four of these villages did not differ regarding the catch composition or the type of fishing gear used (see *Temporal comparison of fish landings*). We tested the normality of the data through a Shapiro-Wilk test and $\log_{10}$-transformed the data if necessary. We used Pearson correlation for normal data and Spearman correlation for data that were non-normal even after transformation.

We compared the number of fishers who mentioned each month as the best fishing season when answering to the question "Which fishing gear do you use and in which season do you fish at each site?" (item 8 from Appendix A) through chi-square tests and a posteriori tests (Z test) analyzing the standardized residuals (see *Fishers' LEK about environmental changes*). We also compared the CPUE (kg fish$\cdot$fisher$^{-1}\cdot$d^{-1}) recorded for fish landings among the sampled months (February, March, June, August, September, and December) through a Kruskal-Wallis (H) analysis. These analyses aimed to check if the months most mentioned by fishers were also those in which the most fish were caught.

Fishers' LEK about environmental changes

We compared the frequencies of the fishers' answers regarding fishes that have decreased or increased in abundance, the alleged reasons for such changes, and the environmental changes that occurred after the dam was built. In these analyses, we considered only answers given by those fishers who were at least 40 years old ($n =$ 157 fishers) and who had been living in the studied region since before the dam was built. These older fishers were already fishing in the region at that time and would therefore have experiential knowledge of changes to the environment and fisheries. The fishers' answers about environmental changes and the reasons for changes in fish abundance were categorized into different classes of answers (Appendix D), and we then compared the frequencies of those answers through a chi-square goodness-of-fit test applied using the WINPEPI software program (Abramson 2004). When the result of this test was significant, we ran an a posteriori test (Z test) to analyze the standardized residuals based on the differences between the observed and expected frequencies to determine which answers contributed positively to the significant differences (Sheskin 2007) based on a sequential Bonferroni adjusted for P values.

Comparison of fishers' ages

We compared the answers about environmental and fisheries changes (Appendix D) provided by the fishers of two age groups: those 40 years and older (who had been living in the studied region and were aged 18 or older at the time that the dam was built) and those less than 40 years of age. The cut-off point at 40 years of age was arbitrarily defined based on the fact that the mean age of the interviewed fishers was 44 years (± 15 years [SD]) and that the youngest fishers were more than 19 years old, whereas the oldest fishers were approximately 80 years old. The minimum age of the interviewed fishers was 19 years (but we interviewed only fishers older than 18 years), indicating that those fishers aged 40 years or older, who were at least 18 when the dam was built, would already have been fishing there and would therefore have personal fishing experience from before the dam was built. Furthermore, the 40 years of age criterion as a cut off to distinguish younger from older informants has also been adopted in other studies based on interviews regarding the use of natural resources, such as in ethnobotany (Figueiredo et al. 1997, Hanazaki et al. 2000, Begossi et al. 2002).

We compared the two age groups through correlations between the number of younger (less than 40 years) and older (40 years and older) fishers who mentioned each category of answer regarding (1) environmental and fisheries changes, (2) fish species that decreased in abundance (and the reasons for these decreases), and (3) fish species that increased in abundance (and the reasons for these increases) after the dam was built (Table 2). We used these correlations to check (1) to what extent the answers provided by fishers 40 years and older (who were included in our analyses of environmental changes, see above) matched the answers provided by younger fishers (not included in analyses) and (2) the extent of intergenerational knowledge transmission from older to younger fishers, which can be more accurately measured by the significance and magnitude of the correlation coefficient (r) (i.e., a higher coefficient indicates stronger agreement between the answers of older and young fishers, indicating knowledge transmission).

Temporal comparison of fish landings

We verified the differences in fish landings before and after the impoundment of the Tocantins River through a nonmetric multidimensional scaling (NMDS) analysis using the Bray-Curtis distance and randomization (10 000 permutations). This analysis was based on the relative proportions of fish biomass represented by the species groups (39 species groups; Table 1) that constituted at least 0.5% of the landings at six comparable sites in the Lower Tocantins River region (Fig. 1): three sampled before (Mocajuba, Icangui, and Ituquara) and three sampled 22 years after (Baião, four grouped villages, and Ituquara) the impoundment. Data from before the construction of the dam were obtained from a previous survey in which fish landings were sampled daily between February 1981 and January 1982 by one or two people in the public markets of the cities of Mocajuba ($n = 6056$ samples) and Tucuruí (data from Icangui, $n = 3348$ samples) and in the village of Ituquara ($n = 3105$ samples; de Mérona et al. 2010). We did not sample exactly the same sites investigated by de Mérona et al. (2010) because, when this study was published, we had already concluded our sampling (from 2006 to 2008). However, we considered the different sites sampled pre- (1981–1982) and post-dam (2006–2008) to exhibit overall similarities regarding the sampling methods applied and fishing characteristics, which make them sufficiently comparable to investigate temporal changes. A similar sampling protocol was used in our survey (2006 and 2008) and in the survey of de Mérona

Table 1. Complete list of fishes included in the NMDS ordination with their estimated prices (US$/kg), when available.

			Sites (Year)					
Local name	US$/kg†	Species‡	Icangui (1981)§	Villages (2007)	Ituquara (1981)§	Ituquara (2007)	Mocajuba (1981)§	Baião (2007)¶
Pescada	1.08	*Plagioscion squamosissimus*	2.6	24.5	14.7	35.6	3.1	25.5
Mapará	1.0	*Hypophthalmus marginatus*	8.9	14.4	12.2	5.8	16.6	8.9
Branquinha	0.7	*Curimata vittata*, *Cyphocharax* spp., *Psectrogaster essequibensis*	16.5	5.3	3.8	13.9	3.4	12.3
Curimata	1.56	*Prochilodus nigricans*	7.2	13.6	7.5	5.6	4.5	14.9
Shrimp	1.56	*Macrobrachium amazonicum*	0.0	0.0	0.0	0.0	38.3	3.4
Aracu	1.51	*Laemolyta* spp., *Leporinus* spp., *Schizodon vittatus*	6.3	4.9	1.9	6.7	2.5	6.5
Tucunaré	1.61	*Cichla kelberi* and *C. pinima*	2.4	5.3	4.4	6.1	2.6	1.3
Pacu	1.06	*Metynnis* spp., *Myleus* spp., *Mylossoma duriventre*	8.5	0.9	7.2	1.2	0.9	1.2
Jaraqui		*Semaprochilodus brama*	13.6	0.0	2.5	0.0	1.2	0.0
Traíra	0.47	*Hoplias malabaricus*	3.8	4.8	3.3	1.4	2.3	1.2
Acará	1.01	*Astronotus ocellatus*, *A. crassipinnis*, *Chaetobranchus flavescens*, *Geophagus altifrons*, *G. proximus*, *Hypselecara temporalis*, *Satanoperca jurupari*	0.9	6.7	1.2	3.0	2.7	1.2
Jatuarana	1.01	*Hemiodus* spp.	7.7	0.7	0.2	3.6	2.7	0.1
Apapá	1.43	*Pellona castelnaeana*	0.8	1.3	4.6	1.7	1.7	4.8
Piranha	0.89	*Pygocentrus nattereri*, *Serrasalmus* spp.	2.4	5.1	1.5	3.4	1.3	0.3
Dourada	2.31	*Brachyplatystoma rousseauxii*	1.2	0.3	3.7	2.2	2.0	3.3
Filhote		*Brachyplatystoma filamentosum*	1.3	0.2	4.9	0.4	1.1	0.0
Icanga		*Cynodon gibbus*	2.0	0.0	4.1	0.0	0.7	0.0
Acari		*Pterigoplichthys joselimaianus*, *Hypostomus* spp.	1.5	0.8	2.8	0.7	0.7	0.0
Mandubé		*Ageneiosus* spp.	0.4	2.9	0.7	0.6	0.6	0.0
Aruanã	1.01	*Osteoglossum bicirrhosum*	0.6	2.9	0.6	0.1	0.7	0.2
Jacundá		*Crenicichla* spp.	0.1	1.5	2.3	0.4	0.2	0.0
Pirarara	1.08	*Phractocephalus hemioliopterus*	0.2	0.5	1.6	1.1	0.4	0.6
Surubim	1.01	*Pseudoplatystoma fasciatum*	1.1	0.3	1.1	0.1	0.5	0.9
Ximbé		*Ageneiosus ucayalensis*	2.2	0.0	1.3	0.5	0.0	0.0
Piranambu		*Pimelodina flavipinnis*	1.0	0.3	1.5	0.0	1.1	0.0
Sardinha		*Triportheus* spp., *Lycengraulis batesii*, *Anchovia surinamensis*, *Pterengraulis atherinoides*	1.4	0.5	0.3	0.4	0.3	0.0
Minguilista		*Rhaphiodon vulpinus*	0.4	0.1	1.0	0.2	1.0	0.0
Cuiú		*Oxydoras niger*	0.0	1.8	0.3	0.3	0.1	0.0
Pirarucu		*Arapaima gigas*	0.3	0.0	0.3	1.6	0.1	0.0
Piramutaba		*Brachyplatystoma vaillantii*	0.4	0.0	1.2	0.3	0.1	0.0
Mandi		*Pimelodus blochii*, *Megalonema platycephalum*	1.5	0.1	0.3	0.0	0.1	0.0
Bacu		Not identified	0.0	0.0	1.3	0.1	0.6	0.0
Bagre		*Goslinia platynema*	0.0	0.0	1.8	0.0	0.0	0.0
Botinho		*Hassar wilderi*, *H. orestis*	0.0	0.1	0.0	1.5	0.1	0.0
Pirapitinga		*Piaractus brachypomus*	0.6	0.0	0.6	0.0	0.4	0.0
Arraia	1.01	*Paratrygon* sp., *Potamotrygon* sp.	0.0	0.1	0.2	0.6	0.2	0.1
Pratiqueira		*Mugil incilis*	0.2	0.0	0.8	0.0	0.0	0.0
Jaú		*Zungaro zungaro*	0.2	0.0	0.5	0.0	0.1	0.0
Tamoatá		*Callichthys callichthys*, *Hoplosternum littorale*, *Megalechis thoracata*	0.0	0.0	0.0	0.0	0.6	0.0
Sum (%)			98	99.8	98.4	99.4	91.7	86.6
Total annual production (Mg)			254.9	141.1	34.5	41.6	251.7	58.2

Note: Numbers are the proportions of the biomass landed by fishers at six sites in the Lower Tocantins River, Brazilian Amazon, before (1981, $n = 12\,509$ fish landings) and after (2007, $n = 687$ fish landings) the dam closure.

† Values estimated from the average market price at the public market of Baião in 2007 (mix of low-valued fish = 0.77 US$/kg).

‡ Authorities of species are in Santos et al. (2004).

§ Data for 1981 from de Mérona et al. (2010) and de Mérona (1990).

¶ Data for 2007 from Hallwass et al. (2011).

et al. (2010) from before the dam was built, recording for each fish landing the type of boat, number of fishers, time fishing, travel time, gear used, fishing spots, and the biomass of fish caught per species (or group of species). The market that we sampled after the dam was built (Baião) is similar to that sampled by de Mérona et al. (2010) before dam construction (Mocajuba) in terms of their geographical locations (Fig. 1) and population sizes. Although the Tucuruí market registered fish landings coming from different sites of the Tocantins River, we considered those fish landings from only the Icangui region in our analyses, which partially overlapped with the region exploited by the fishers from the four villages that we studied in the Lower Tocantins River (Fig. 1). We performed NMDS followed by analysis of similarities (ANOSIM) to compare the compositions of the fish catches among the four fishing villages that we studied after the dam was built (which were grouped and compared with the Icangui region), considering the four sampled seasons as replicates (flooding, high, receding, and low water). According to this analysis, the fish catches did not differ among the four fishing villages (global $R = 0.03$, $P = 0.34$), which indicated that there was no significant spatial variation in the fish catches. In 1981 and 1982, gill nets were the main type of fishing gear used at Icangui and Ituquara (67% and 75%, respectively), while at Mocajuba, the main gear types were beach seines (30%), *pari* (fixed fish trap) (19%), gill nets (15%), *matapi* (shrimp trap) (13%), and longlines (12%) (de Mérona et al. 2010). Similarly, in the four fishing villages studied after the dam was built (which were grouped and compared with the Icangui region), gill nets were used in 65% of fish landings, and hooks (pole and line, hand line, and long line) were used in 29% of fish landings; in Ituquara, in the present study, gill nets were also found to be the main type of fishing gear used (53% of fish landings), and hooks were associated with 44% of fish landings in the recent samples, obtained after the dam was built (Appendix E). However, gill nets (92%) were the main type of fishing gear used by fishers in Baião after the dam was built, while when the similar market, Mocajuba, was sampled before the dam was built, the fishers there used several types of fishing gear (de Mérona et al. 2010). This difference and the predominance of gill nets in the Baião market could be at least partially due to underreporting by middlemen, who buy fish in fishing villages to sell in the market and may therefore not be completely aware of the types of gear used (Hallwass et al. 2011).

We could not perform an ANOSIM to test for differences between the two groups (before and after the impoundment) because we had only three replicates for each group. With such a small number of replicates, the test would run only 10 distinct permutations and would have reduced power to detect a difference between groups (Clarke and Warwick 2001). Nevertheless, we conducted a similarity percentage analysis (SIMPER) between the two groups of sites (before and after the impoundment) to determine which fish species groups explained the most dissimilarity between the groups of sites. These results were compared with interview data on which fish species had increased or decreased in abundance according to the fishers. We performed the NMDS and SIMPER analyses using the PRIMER 6 software program (Clarke and Gorley 2006).

Results

Fishers' profiles

The interviewees' ages ranged from 19 to 89 yr, with a mean age of 44 yr (± 15 yr [SD]) and a mean residence time in the region of 35.6 yr (±15.4 yr). Although only 4% of the fishers were illiterate, most of them (63%) had frequented school from only one to four years. Fishing was the main economic activity of the interviewees ($n =$ 295 people), followed by agriculture ($n = 192$ people), but many of them ($n = 189$ people) engaged in both activities. The fishers' fathers had also practiced fishing ($n = 211$ people), agriculture ($n = 168$ people), or both activities ($n = 113$ people). All of the interviewed fishers reported that they consumed the fish they caught, and most of them (85.3%) also sold their catches.

Do fishers' answers reflect fisheries data?

The fish mentioned by larger numbers of the interviewed fishers were also those that were caught most in fishing landings ($r_S = 0.73$, $n = 33$ species, $P <$ 0.001; Fig. 2). The types of fishing gear mentioned by more fishers were also those that were most often used in fish landings ($r_S = 0.74$, $n = 9$ gear types, $P = 0.02$): gill nets were the main type of gear cited in the interviews (n $= 258$ fishers, or 86%) and used by fishers ($n = 379$ fish landings, or 63%), while fishing poles and hand lines were both mentioned less often ($n = 138$ fishers, or 46%, and $n = 30$, or 10%, respectively) and used less often ($n =$ 132 landings, or 22%, and $n = 84$ landings, or 14%, respectively). Indeed, even the mesh sizes of the gill nets that were mentioned by more fishers (7 and 8 cm between opposite knots) were also used more often by fishers ($r_S = 0.82$, $n = 11$ sizes, $P < 0.001$, Appendix F).

The interviews indicated seasonal changes in fish abundances ($\chi^2 = 172.1$, df $= 11$, $P < 0.001$): the months most mentioned as fishing periods were May ($n = 107$ fishers, $z = 9.1$, $P < 0.001$), June ($n = 69$, $z = 3.4$, $P =$ 0.005), August ($n = 67$, $z = 3.1$, $P = 0.01$), and September ($n = 65$, $z = 2.8$, $P = 0.04$). However, the CPUE ($kg \cdot fisher^{-1} \cdot d^{-1}$) recorded for the fish landings did not differ among the months sampled ($H = 2.74$, df $= 5$, $P =$ 0.74).

Which environmental changes were most cited by fishers?

The frequencies of the answers given by fishers who were 40 years and older ($n = 157$) about the fishes that had increased in abundance after the impoundment differed ($\chi^2 = 571.7$, df $= 13$, $P < 0.001$): the answer given by most of the fishers was "none" ($z = 20.3$, $P < 0.001$),

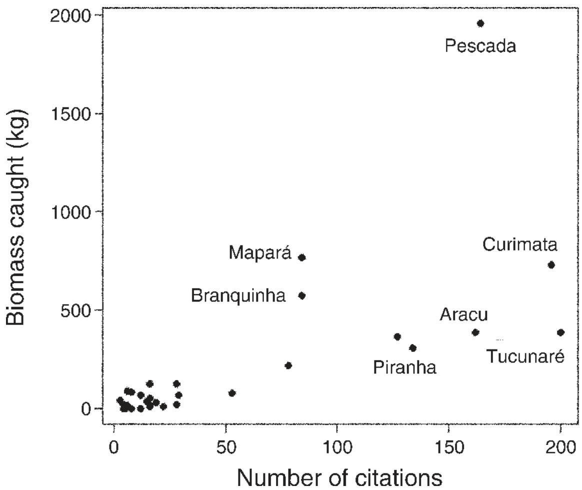

FIG. 2. Correlation plot for the 33 fishes caught in fish landings (biomass) and mentioned by fishers in interviews (number of fishers) in the Lower Tocantins River, Brazilian Amazon. The most often caught and most often mentioned fishes are indicated with their local names; the scientific names of the fish are given in Tables 1 and 3.

followed by *pescada* (*Plagioscion squamosissimus*; $z = 7.1$, $P < 0.001$) and *curimata* (*Prochilodus nigricans*; $z = 3.0$, $P = 0.04$; Fig. 3A). The reasons (Appendix D) given by fishers to explain such increases in the abundances of some fish after the impoundment also differed ($\chi^2 = 125.3$, df = 9, $P < 0.001$): most of the fishers ($n = 32$ fishers) said that they did not know ($z = 8.8$, $P < 0.001$) or that the fish have adapted to the new environment ($n = 20$ fishers, $z = 4.5$, $P < 0.001$). The fishers' answers also differed regarding the fishes that had decreased in abundance after the river impoundment ($\chi^2 = 1549.9$, df = 44, $P < 0.001$): the most-cited fishes were *jaraqui* (*Semaprochilodus brama*; $z = 26.5$, $P < 0.001$), *pacus* (*Myleus* and *Methynnis* spp.; $z = 15.7$, $P < 0.001$), *pratiqueira* (*Mugil incilis*; $z = 14.3$, $P < 0.001$), *piabanha* (*Brycon falcatus*; $z = 8.3$, $P < 0.001$) and *pirapitinga* (*Piaractus brachypomus*; $z = 7.8$, $P < 0.001$, Fig. 3B). The reasons (Appendix D) provided by the fishers as to why some fish had decreased in abundance differed ($\chi^2 = 105.2$, df = 8, $P < 0.001$): most of the fishers ($n = 56$ fishers) stated that fish were trapped above the dam ($z = 6.7$, $P < 0.001$) or that the dam caused fish shortages ($n = 39$ fishers, $z = 3.2$, $P < 0.01$). Additionally, the fishers' answers differed regarding the environmental changes that occurred after the impoundment (Appendix D; $\chi^2 = 247.2$, df = 8, $P < 0.001$): most of the fishers ($n = 101$ fishers) mentioned decreases ($z = 11.1$, $P < 0.001$) and even local extinction ($n = 62$ fishers, $z = 4.5$, $P < 0.001$) of some fishes, whereas a smaller number cited a decrease in the quality of river water ($n = 53$ fishers, $z = 3.0$, $P = 0.02$).

Do older and younger fishers have similar knowledge?

The answers given by the younger (less than 40 years) and older (40 years and older) fishers were all positively correlated, indicating that the fishers from different age groups had similar overall knowledge (Table 2), which may be at least partially related to intergenerational knowledge transmission. The positive correlations also indicated that the answers provided by younger fishers matched those of older fishers. Therefore, we did not lose a considerable amount of information by not including younger fishers in the analyses of environmental changes.

Did fish landings change after the impoundment?

The NMDS ordination and the SIMPER analysis indicated possible temporal changes in the compositions of fish landings between the sites sampled before and 22 years after the impoundment (Fig. 4). According to the SIMPER analysis, the sites sampled before and after the impoundment exhibited an average dissimilarity of

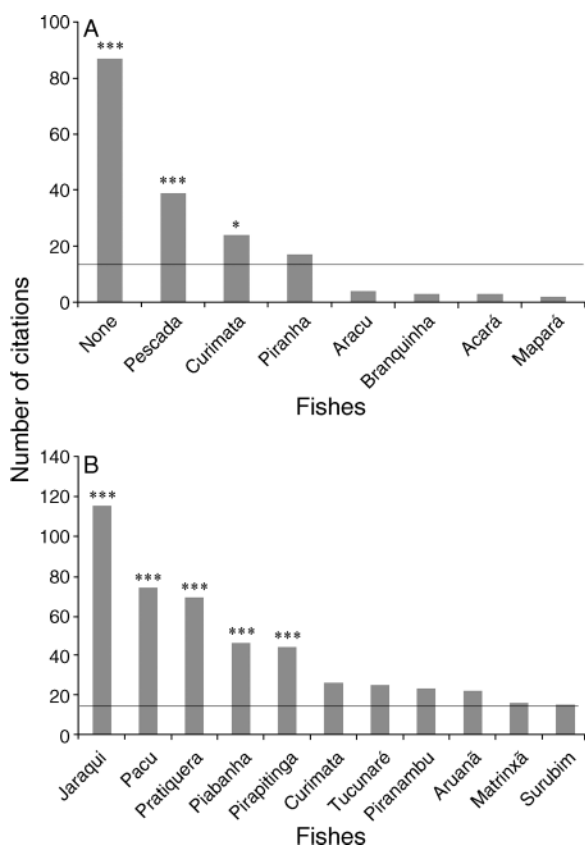

FIG. 3. Fishes mentioned by fishers who were at least 40 years old at the time of the interview ($n = 157$ fishers) in the Lower Tocantins River, Brazilian Amazon: (A) fishes that were mentioned by two or more fishers as having increased in abundance after the impoundment (14 fishes); (B) fishes that decreased in abundance that were mentioned by at least 15 fishers (45 fishes). Asterisks indicate statistical significance according to a residual standardized analysis (z test). Fish are identified by their local names; scientific names are given in Tables 1 and 3. The horizontal line indicates the expected frequency of citations if all categories are cited equally.
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

TABLE 2. Correlations between the frequency of answers to interviews given by fishers younger (less than 40 years, $n = 130$) and 40 years and older ($n = 157$) who have been living in the studied region since before the dam was built, in the Lower Tocantins River, Brazilian Amazon.

Question	r†	r_S‡	P	n§
Changes after the impoundment	0.89		<0.01	15
Fishes that decreased in abundance		0.84	<0.01	60
Reasons why fishes decreased in abundance	0.87		<0.01	16
Fishes that increased in abundance		0.59	<0.01	23
Reasons why fishes increased in abundance		0.54	0.02	17

† Pearson correlation, after data were $\log_{10}$-transformed to achieve normal distribution.
‡ Spearman correlation, non-normal data.
§ Number of answers included in the correlation analysis.

51.4%; the sites sampled after the impoundment were more homogenous in terms of fish landings (69% similarity) compared to those sampled before the impoundment (50% similarity). The fishing resources that contributed the most to the differences between the sites sampled before and after the impoundment were the fish *pescada* and the shrimp *Macrobrachium amazonicum* (Table 3).

The CPUE decreased in the four fishing villages studied after the impoundment compared to similar sites sampled before the impoundment, although the CPUE increased in the city of Baião (Table 4). The total fish biomass production of the three regions sampled after the impoundment was less than half of what was landed before the impoundment, despite the human population growth (of approximately 10 times in Ituquara and almost five times in Baião) over the last 22 years (Table 4).

DISCUSSION

LEK, fisheries, and management

Fishers' LEK did not differ between older and younger fishers in the Lower Tocantins River (Table 2), indicating that at least part of fishers' knowledge might have been transmitted from older generations (Berkes 1999, Diamond 2001): most of the fishers' fathers were also fishers. The fishers' answers regarding environmental changes that negatively affected fishing resources were strongly correlated between the two age groups (high values of r or r_S, Table 2). This correlation suggests that the LEK about environmental changes impacting fishers' livelihoods, such as the river's impoundment, could have been more efficiently transmitted among the studied fishers, as has been observed in other studies (Berkes and Turner 2006, Rochet et al. 2008). Therefore, these results indicate that the studied fishers do not show the cognitive shortcomings of shifting baseline syndrome on environmental perceptions, in the form of "generational amnesia" (younger people fail to recognize past changes; Papworth et al. 2009). Because reported changes by both older and younger fishers agreed with fisheries data (see *Do fishers' answers reflect fisheries data?*), we assumed that interviewed fishers did not show personal amnesia (all people fail to recognize changes) nor memory illusion (perception of changes that did not occur), as defined by Papworth et al. (2009).

Knowledge regarding the fish targeted (e.g., those that are most often caught) and the primary types of fishing gear used is of paramount importance for the proper management of fisheries, but even these basic data are usually unavailable in tropical developing countries (Johannes 1998, Begossi 2008). In the Lower Tocantins River, interviews with fishers provided reliable data about the main fishes caught and the most-used type of fishing gear. The fish most often mentioned by the fishers and caught in fish landings, such as *pescada* and *curimata*, could be included in future management plans. It is possible that these two fish species can cope with reservoir conditions and be resilient to fishing pressure, as catches of these two fishes increased in the fisheries of the Lower Tocantins River after the impoundment (Table 1). Furthermore, *pescada* (introduced from the Amazon Basin) and corimbata (*Prochilodus lineatus*) are also the fishes that are most caught by fishers in impounded southeastern Brazilian rivers and reservoirs (Silvano and Begossi 2001, Agostinho et al. 2008). However, further studies are needed, first, to verify the extent to which the populations of these fishes have been able to cope with increased fishing pressure, and second, to provide data on the migratory and spawning behavior of these fishes. LEK data obtained from coastal fishers combined with limited fish landing data and life history information have previously been used to indicate which fish species are most vulnerable to fishing pressure and, thus, more in need of management actions in the Philippines (Lavides et al. 2010).

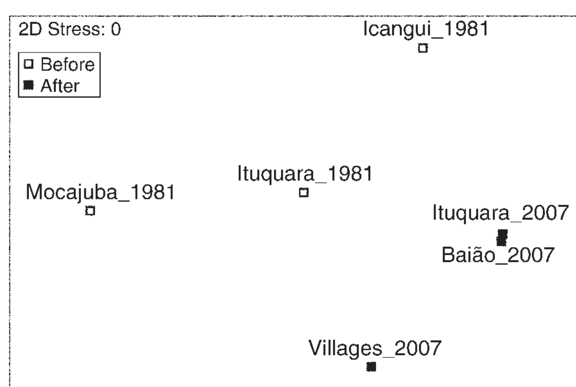

FIG. 4. NMDS ordination (stress = 0) plot based on the composition of fish (percentage of biomass) caught by small-scale fishers at sites sampled before and after the impoundment in the Lower Tocantins River, Brazilian Amazon (Table 1). Villages_2007 refers to the four villages sampled in 2007 (Calados, Açaizal, Joana Perez, and Umarizal).

TABLE 3. Fishing resources and their contribution for dissimilarity (SIMPER analysis) between sites sampled before (1981, $n =$ 12 509 fish landings) and after (2007, $n = 687$ fish landings; Fig. 4) the impoundment in the Lower Tocantins River, Brazilian Amazon.

Local names	Species†	Abundance‡		Mean dissimilarity§	Contribution (%)¶
		1981	2007		
Pescada	*Plagioscion squamosissimus*	6.8	28.5	11.2 ± 2.8	21.9
Shrimp	*Macrobrachium amazonicum*	12.8	1.1	6.9 ± 0.7	13.4
Branquinha	Curimatidae	7.9	10.5	3.4 ± 1.6	6.6
Curimata	*Prochilodus nigricans*	6.4	11.4	3.0 ± 1.6	5.9
Jaraqui	*Semaprochilodus brama*	5.8	0	3.0 ± 1.0	5.8
Mapará	*Hypophthalmus marginatus*	12.6	9.7	2.4 ± 1.4	4.6
Pacu	*Myleus* and *Methynnis* spp.	5.5	1.1	2.4 ± 1.4	4.6
Jatuarana	*Hemiodus* spp.	3.5	1.5	1.6 ± 1.2	3.2
Aracu	Anostomidae	3.5	6.1	1.5 ± 1.6	2.8
Acará	Cichlidae	1.6	3.7	1.2 ± 1.1	2.3
Tucunaré	*Cichla* spp.	3.1	4.2	1.2 ± 2.2	2.3
Icanga	*Cynodon gibbus*	2.2	0	1.2 ± 1.5	2.2
Filhote	*Brachyplatystoma filamentosum*	2.4	0.2	1.1 ± 1.2	2.2
Piranha	Serrasalmidae	1.7	2.9	1.1 ± 2.2	2.2

Note: We show only those fishing resources that contributed with more than 2% of the overall dissimilarity.

† Authorities of species are in Santos et al. (2004).

‡ Simple mean abundance of the proportion of biomass of fishing resources landed in the three sites sampled before (1981) and the three sites sampled after (2007) the dam was built (Table 1).

§ Mean dissimilarity and standard deviation between the three sites sampled before (1981) and after (2007) the dam was built.

¶ Contribution of each fishing resource to the dissimilarity between the two groups of sites (1981 and 2007).

Management measures in freshwater fisheries usually regulate or even forbid the use of specific types of gear, such as gill nets. The gear restrictions may be complete (banning of the gear), seasonal, or based on gear specifications, such as gill net mesh sizes (Gewin 2004, Almeida et al. 2009, Khumsri et al. 2009). According to our interview results, which agreed with the fish landing data, gill nets with mesh sizes of 7 and 8 cm were the gear most used by the studied fishers in the Lower Tocantins River. This information on fishing gear usage could help managers to estimate the potential impact of gill nets on fish populations as well as the possible socioeconomic impacts of restrictions on gear use. For example, two fishing communities located in the Mamirauá and Amanã reserves (Solimões River, Brazilian Amazon) differ in their use of gill nets, and applying the same restrictions on this type of gear would not be equally feasible at both sites (MacCord et al. 2007). There are currently few official (e.g., governmental) management measures in the Tocantins River; such measures are issued by the central Brazilian governmental management agency in a top-down fashion. These measures, which have been weakly enforced and with which there is low compliance by local fishers, usually address closed fishing seasons and gear restrictions and are not tailored to specific fishes. A promising way to increase management effectiveness in such a context would be to involve local fishers in co-management systems that consider fishers' LEK (McGrath et al. 2008). Such initiatives have already begun to be

TABLE 4. Population size, mean catch per unit of effort (CPUE; ±SD) and total annual fish production of sites sampled before (1981) and after (2007) the impoundment in the Lower Tocantins River, Brazilian Amazon.

Sites	Year	Population†	CPUE (kg·fisher^{-1}·landing^{-1})	Fish production (Mg)
Mocajuba	1981‡	5 600	26.1 ± 6.3	251.7
Icangui	1981‡		34.8 ± 7.9	254.9
Ituquara	1981‡	670	7.2 ± 1.1	34.5
Total				541.1
Baião	2007§	26 190	48.6 ± 47.6	58.2
Four villages	2007§		6.6 ± 8.1	141.1
Ituquara¶	2007§	7 000	6.36 ± 7.5	41.6
Total				240.9

† Estimated population sizes in 1981 from de Mérona et al. (2010) and in 2007 from Brazilian national census (http://www.ibge.gov.br/home/estatistica/populacao/contagem2007).

‡ Data from de Mérona (1990) and de Mérona et al. (2010), collected daily from February 1981 to January 1982; the sample sizes were: Mocajuba, $n = 6056$ fish landings; Icangui, $n = 3348$ fish landings; and Ituquara, $n = 3105$ fish landings. However, mean and standard deviation were calculated for the 12 months sampled, based on monthly CPUE data.

§ Data from Hallwass et al. (2011), collected during 67 days in Baião ($n = 86$ fish landings), four villages ($n = 381$ fish landings), and Ituquara ($n = 220$ fish landings). Mean and standard deviation were calculated based on data for each fish landing.

¶ Estimated population size from J. A. C. Andrade (unpublished report to Eletronorte), based in 1000 families with an average of seven people per family.

PLATE 1. (Left) Children playing in the sunset in the waters of the Tocantins River, Brazilian Amazon. (Right) A fisherman repairing gill nets (the most used fishing gear among the studied fishers) in the Ituquara fishing village, Lower Tocantins River, Brazilian Amazon. Photo credits: R. A. M. Silvano.

implemented in the Lower Tocantins River, involving some of the studied fishing villages (Silvano et al. 2009, Lopes et al. 2011). The information on fishing dynamics that we provided based on fishers' LEK could be equally (perhaps even more) applicable to co-management systems including local fishers in the Tocantins River and other Amazonian regions. Indeed, LEK surveys can improve the dialogue and collaboration between researchers and resource users, making the implementation of monitoring and management techniques faster and more locally viable (Begossi 2008, Danielsen et al. 2010, Daw et al. 2011).

Interviews with fishers have previously been used to analyze fishing dynamics in the Brazilian Amazon (Begossi et al. 1999, Almeida et al. 2009), but interview data have not been compared to biological or fisheries data collected in the same time and place. The observed positive and significant correlation between the interview and fish landing data in the Lower Tocantins River indicate that the fishers' answers accurately reflect their behavior, thus providing additional support regarding the strength of the interview method. The complexity of freshwater and coastal small-scale fisheries demands decentralization of management to tailor management measures to the local level (Begossi 2008), but local data are usually scarce. The readiness, reliability, and low cost of interviews with resource users have the potential to improve resources management at both local and regional scales (Salomon et al. 2007, Jones et al. 2008). Our results therefore reinforce the potential applications of fishers' LEK as a complementary (and often unique) data source on small-scale fisheries in tropical developing countries, where there is usually a lack of financial resources and scientific data (Johannes 1998, Silvano and Valbo-Jorgensen 2008, Lavides et al. 2010). Data from fishers' LEK could be also useful as an input or comparative baseline to quantitative fishery models of temporal trends on fish catches (Rochet et al. 2008, Daw et al. 2011).

We also observed some minor inconsistencies between the interview and fish landing data obtained for the Tocantins River: the main fish caught in fish landings (*pescada*) was not the one most often mentioned by the interviewed fishers, and *mapará* (*Hypophthalmus marginatus*) and *branquinha* (Curimatidae, many species) were comparatively caught more often (more biomass) but mentioned less often than *tucunaré* (*Cichla* spp.) and *curimata* (Fig. 2). This discrepancy may be related to the higher market price *of tucunaré* and *curimata* (1.6 US$/kg) compared with *pescada* (US $1.1/kg), *mapará* (US $1/kg), and *branquinha* (US $0.7/kg; Table 1). Preferred or high-value fishes are usually mentioned more often and are better known by fishers (Poizat and Baran 1997, Silvano and Begossi 2002). Therefore, one limitation of interview-based data could be that it may slightly overestimate the landed biomass of highly valued fishes. It could also be possible that most cited fishes have larger sizes, as fishers may more readily remember large fish than smaller ones. We performed a correlation between the number of fishers who cited each fish species (or group of species) and the mean standard length (in cm) of these fish species for 25 fishes (including the most cited ones) using fish length data from fish samples collected in lakes in the study region (Silvano et al. 2009). The correlation was nonsignificant ($r = -0.23$, $n = 25$ species, $P = 0.27$), indicating that fish size was not related to the number of fishers who mentioned each fish.

Most of the interviewed fishers stated that fish are more abundant during the months of May, June, August, and September, when the water level decreases in the Tocantins River (low and receding water seasons; Ribeiro et al. 1995). Other surveys in the Brazilian Amazon also report higher fishing yields during the low water season (Begossi et al. 1999, Cerdeira et al. 2000, Cetra and Petrere 2001, MacCord et al. 2007). However, although our interview data from the Tocantins River reflected the overall pattern of Amazonian fisheries, they did not agree with the fish landing data from the same region. The CPUE of the recorded fish landings did not differ seasonally, which may be because fishers change their fishing gear seasonally, using hand lines more often during the high-water season (Hallwass et al. 2011). This change may increase fishing yields during the high-water season, as the efficiency of hand lines is less affected by the lower fish densities that occur during floods compared to gill nets. Another possible explanation for the observed mismatch between the interview and fish landing data is that we sampled fish landings within a relatively short time interval (one year), while fishers' LEK may consider the average fishing yields over many years. Resource users' LEK usually appears to involve knowledge accumulated over broad temporal scales, such as decades (Salomon et al. 2007, Lavides et al. 2010). Aswani and Hamilton (2004) observed a similar discrepancy between fishers' LEK and fish landing data regarding the influence of the lunar cycle on fish catches in the Solomon Islands in the South Pacific. Similarly, in Seychelles trap fisheries, the abundance trends of fish catches and reef fish over a 10-yr period differ between records of interviews with fishers, underwater visual censuses of fish abundance, and systematic recording of fish landings (Daw et al. 2011). Disagreements between LEK and biological data do not necessarily limit the utility of LEK but can be viewed as an opportunity to advance knowledge by providing new information (Silvano and Valbo-Jorgensen 2008, Silvano and Begossi 2010, Daw et al. 2011). For example, we can formulate the hypothesis that there is a seasonal pattern of fish abundance in the Lower Tocantins River, but that such a pattern may not be detected over a short time scale (i.e., one year of sampling fish landings). In the North Atlantic, fishers' LEK has been found to correspond better to biological data on the scale of years, indicating that LEK may be useful as an early warning sign of ecosystem changes (Rochet et al. 2008).

LEK and environmental changes

According to the interviewed fishers of the Lower Tocantins River, the main environmental change after the river's impoundment was an overall decrease in fish abundance. The fishers also stated that some fishes increased and others decreased in abundance, thus indicating changes in the composition of fish landings after the impoundment. These general ecological consequences of the Tocantins River impoundment reported by fishers were consistent with our fish landing data and with previous studies. For example, the biomass of *pescada* increased in fish landings after the impoundment (Table 3), and this fish was also the most mentioned by the interviewees as having increased in abundance (Fig. 3A).

Most of the fishers mentioned a decrease in the abundance of *jaraqui*, and some fishers ($n = 65$ fishers) even stated that this fish had disappeared from the Lower Tocantins River after the impoundment. This fish was not, in fact, represented in the fish landings sampled after the dam was built, but it accounted for 13.6% of the fish biomass landed in the Icangui region before the impoundment (Tables 1 and 3). Additionally, *jaraqui* is one of the main fishes caught in the Middle Tocantins River, upstream from the dam (Cetra and Petrere 2001). *Jaraquis* (*Semaprochilodus* spp.) undergoes long spawning migrations, as recorded in the Negro River in the Brazilian Amazon (Ribeiro and Petrere 1990). Our results therefore indicate that the dam may have negatively affected this fish downstream, possibly by interrupting its migratory route. This type of an ecological effect would agree with fishers' statements that "fish would be trapped" in the reservoir, indicating the possible local extinction of a fish in the Tocantins River downstream from the dam. Freshwater fish extinctions downstream from dams 20 years after the impoundments have also been observed in Australia (Gehrke et al. 2002) and in China (Zhong and Power 1996). Although expected, local or regional fish extinctions caused by dams have not been well documented in many tropical regions due to the lack of data from before and after impoundments.

Fishers also stated that *pacus* decreased in abundance after the impoundment in the Lower Tocantins River. These and other fishes from the order Characiformes (including *jaraqui*) are usually adversely affected by changes in water flow caused by impoundments, most likely due to reduced larval survival in their floodplain nursery grounds (Ponton and Vauchel 1998, Agostinho et al. 2004). The interviewed fishers also mentioned a decrease in abundance for some fishes, such as *pratiqueira*, *piabanha*, and *pirapitinga*, that were not caught after the impoundment (Table 1) but accounted for less than 1% of fish biomass landed before the impoundment (de Mérona et al. 2010). This finding indicates that the abundance of these fishes could have been decreased even before the dam was built. The catches of shrimp also decreased in fish landings in the Lower Tocantins River after the impoundment (Table 3), but this decrease was not cited by the interviewed fishers, possibly because shrimp are landed mostly in the city markets (Baião and Mocabuja), rather than in the studied villages where we conducted the interviews (Table 1). Large migratory catfishes (Pimelodidae) have been negatively affected by dams in Brazilian rivers, including the Brazilian Amazon (Barthem et al. 1991, Agostinho et al. 2004). However, the interviewed fishers of the Lower Tocantins River did not mention large catfishes, which were also not recorded in the fish landings either before or after the impoundment. Amazon fishers consider catfishes to be a food that is taboo and usually do not consume them (Begossi et al. 2004), which could explain why they were not cited or caught by the interviewed fishers. Therefore, our interview results may underestimate the effect of the Tocantins River impoundment on large catfishes. Fishers' LEK regarding the temporal trends of fish abundances in the Lower Tocantins River may be more accurate for some species, such as *pescada*, *jaraqui*, and *pacu*, than for others, such as *pratiqueira*, shrimps, and large catfishes. Differences in the degree of fishers' LEK among fish species have also been observed in previous works (Silvano et al. 2006).

Other studies have reported changes in the composition of fish communities downstream from dams (Zhong and Power 1996, Ponton and Vauchel 1998, Gehrke et al. 2002), including a trophic reorganization of the fish communities in the Lower Tocantins River (de Mérona et al. 2001). This type of ecological change is consistent with the pattern observed in this survey both from interviews and based on fish landings in the Lower Tocantins River, i.e., that there was a decrease in planktivorous (*H. marginatus*), herbivorous (*Myleus* and *Methynnis* spp.), and detritivorous (*S. brama*) fishes and a concomitant increase in piscivorous (*P. squamosissimus*) fishes after the impoundment (Table 3).

The interviewed fishers also mentioned deterioration of water quality and changes in water levels as major environmental changes that occurred after the impoundment of the Tocantins River. Although we could not analyze the temporal trends in water quality in the Lower Tocantins River, the answers of these fishers' agreed with information from the literature on the effects of reservoirs on water quality (Petrere 1996, Zhong and Power 1996, Ponton and Vauchel 1998, de Mérona et al. 2001, 2010, Agostinho et al. 2004).

Our results from interviews and from temporal comparison of fish landing data quantitatively indicated that there were reductions in the CPUE and annual fish production in the Lower Tocantins River after the impoundment, potentially affecting the local economy, which is mostly based on fisheries and small-scale agriculture (Hallwass et al. 2011). Such reductions in fishing yields in the Lower Tocantins River could be related to the observed changes in the composition of fish landings, in addition to decreases and even local extinctions of commercial fishes. The relatively high CPUE observed in the Baião public market after the impoundment was possibly overestimated due to including not only fishers, but also intermediaries, who buy fish from different fishers and then resell those fish in the market (Hallwass et al. 2011). Decreases in fish size and fisheries production have also been observed in other impounded rivers in Australia (Gehrke et al. 2002) and China (Zhong and Power 1996). Therefore, fishers' LEK properly acknowledges and aids in the quantification of the ecological and socioeconomic effects of the impoundment of large rivers, both in Brazil and elsewhere. Furthermore, the LEK of fishers and other resource users could also be useful in subtropical and temperate rivers. For example, Zukowski et al. (2011) applied recreational fishers' LEK to improve the available database and to test hypotheses about fishing regulations for a crayfish species in southern Australian rivers; in another survey, the LEK of boat guides provided useful quantitative observations on the foraging behavior of a predator avian species in a regulated river in Colorado, USA (Stevens et al. 2009). Our results reinforce arguments from other recent studies that mixing fishers' LEK with biological data may represent a promising approach for improving our knowledge of ecological patterns to inform policies aimed at fisheries management and the conservation of aquatic resources (Silvano et al. 2006, 2008, Salomon et al. 2007, Rochet et al. 2008, Lavides et al. 2010, Daw et al. 2011).

Resource users' LEK as reported in interviews may be susceptible to political influences, which may compromise the reliability of the data. In the Lower Tocantins River, many of the interviewed fishers said that they do not know the causes of increases or decreases in fish abundance (Appendix D). These responses indicated that most of the interviewed fishers honestly admitted when they do not know or cannot provide information on a given subject. However, we evaluated a strong, sudden, and controversial environmental impact in the studied region (the impoundment of a large river), which may be better perceived by fishers. Gradual environmental changes may be less perceptible to resource users and less detectable in LEK surveys. Similarly, French fishers usually do not cite the causes of changes in fish assemblages along the North Atlantic coast (Rochet et al. 2008). Therefore, quantitative sampling based on structured interviews may not be the best method to assess the ecological processes underlying patterns of gradual environmental change. Nevertheless, such limitations may be circumvented by employing a qualitative approach that focuses on more experienced LEK holders. For example, in Alaska, interviews with elders were found to provide useful and novel information on ecological processes (overfishing and increased predation) that cause declines in the populations of marine invertebrates (Salomon et al. 2007). Along the Brazilian southern Atlantic coast, interviews with more experienced fishers (40 years and older) provided useful information on the reproduction and migration of marine fishes (Silvano et al. 2006). Other quantitative studies confirm that fishers' LEK accurately indicates decadal decreases in the abundance of exploited fishes (Rochet et al. 2008), fish species that disappeared from catches (Lavides et al. 2010) and the status of overexploited stocks of important commercial fishes (Saenz-Arroyo et al. 2005).

Conclusions

In this study, we demonstrated that recording fishers' LEK through interviews could serve as a fast, efficient, reliable, and affordable approach to register both current resource use and temporal environmental changes. The obtained interview data accurately reported fishing activities, such as regarding the types of target species and fishing gear used, and may therefore serve as a valuable input for fisheries management and research when fish landing data are not available. This study is one of the first to record fishers' LEK about environmental changes caused by a large dam in a tropical river and to cross-check the interview data with fisheries data. By doing so, we provided information that will be useful for implementing impact assessments and fisheries management: we observed changes in the composition of fish landings (through both increases and decreases in the abundances of fish species groups), the possible local extinction of a commercial fish and an overall decrease in fishing production after the river's impoundment. Our results therefore provide support for the hypothesis that future large dams being planned in the Brazilian Amazon and in other tropical rivers may have ecological and socioeconomic impacts (Fearnside 1999) that would affect people living hundreds of kilometers downstream from the location where the dam is to be built. These environmental changes caused by river impoundment may compromise the food security of people who rely heavily on fishing in the Tocantins River (Hallwass et al. 2011), in the Brazilian Amazon (Silvano et al. 2009), and in other regions. A political implication of these results is that areas downstream from large reservoirs should be included in mitigation and compensation measures.

Although fishers' LEK should be critically evaluated, there is much room for including LEK in biological research and management (Huntington 2011). Our results not only reinforce the established applications of fishers' LEK to fisheries and ecological sciences but also expand these applications to include an assessment of the effects of dramatic environmental change (impoundment of a river) over large spatial and temporal scales.

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Supplemental Material

Appendix A

Questionnaire used in interviews with fishers from nine villages along the Tocantins River, Brazilian Amazon (*Ecological Archives* A023-020-A1).

Appendix B

Survey used to quantify the species and biomasses of fish caught and type of fishing gear used by fishers in the Lower Tocantins River in the Brazilian Amazon (*Ecological Archives* A023-020-A2).

Appendix C

Correlations between the fish landed (biomass) and mentioned in interviews for each village (*Ecological Archives* A023-020-A3).

Appendix D

Categories of answers of the interviewed fishers to questions about environmental changes and the reasons for such changes in fish abundance (*Ecological Archives* A023-020-A4).

Appendix E

Frequency of the type of fishing gear used (%) in fish landings in the five studied fishing villages (*Ecological Archives* A023-020-A5).

Appendix F

Correlation plot of the frequencies of 11 distinct gill net mesh sizes observed and reported by fishers (*Ecological Archives* A023-020-A6).