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Beyond fishermen's tales: contributions of fishers' local ecological knowledge to fish ecology and fisheries management

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Abstract Studies investigating the local ecological knowledge (LEK) held by fishermen about the fishing resources have indicated that fishermen's LEK may have the potential to improve fishery management, by providing new information about the ecology, behavior and abundance trends of fish and other aquatic animals. Our major aim is to undertake a brief review of published ethnoichthyological studies with a focus on coastal Brazilian fisheries and freshwater fisheries in both Brazil and Southeast Asia. Based on such review, we provide 29 hypotheses on fish ecology based on fishermen's LEK and compare them with what is already known from the biological literature, using an arbitrary 'likelihood' measure: "Low likelihood" corresponded to unexpected hypotheses, which contradict existing biological data. "Medium likelihood" corresponded to hypotheses that could not be compared to available scientific knowledge. Hypotheses that agree with scientific data were considered as "High likelihood". We therefore discuss these three categories of hypotheses about several distinct topics, such as migration, reproduction, feeding habits, abundance patterns, ecological relationships between fish and their predators, and fishing pressure. Our results may contribute to the fisheries management and research in the studied regions and other similar places, besides raising the interest of biologists to properly include fishermen's LEK when planning and conducting fisheries surveys.

Keywords Amazon Basin · Brazilian coast · Ethnobiology · Fish ecology · Fisheries management · Human ecology · Mekong River

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1 Introduction

Tropical artisanal fisheries present special challenges to sustainable management: they often take place in remote areas with poorly developed infrastructure, the fishermen employ a variety of fishing gear to exploit many different species; fisheries are the main (or the sole) source of cash and income for thousands of poor people; in many cases fishing is a part time occupation mainly for subsistence, and governments are usually ill prepared to gather appropriate data and to enforce fishing regulations (Pauly et al. 2002). In this sense, Johannes (1998) argue that for many tropical coastal fisheries in developing countries it may simply not be feasible to gather the detailed biological data that are required to support fishery management initiatives, due to the lack of funding and trained biologists. Therefore, the solution, at least in the short term, would be a sort of "data-less" management approach, building on available data, to a large extent relying on the knowledge held by local fishermen (Johannes 1998).

In a pioneering ethnoichthyological survey, Morril (1967) observes that fishermen from the Virgin Islands are always talking about fish, constantly discussing fish ecology and behavior. The same is true among artisanal fishers in coastal and inland water areas throughout the world. These fishermen's tales may disclose information about size and abundance of fish caught, fish behavior, past situation of fisheries and of fish resources and so on. Scientists tend to regard such information anecdotal and thus of lesser value, but there is a growing recognition that it may in fact provide an excellent source of information that can complement fishery data collected through conventional approaches, for example about past abundance patterns of target fish, long before the onset of data recording by scientists (Pauly 1995; Saenz–Arroyo et al. 2005). It is indeed possible that many biologists have been benefiting from fishermen advice when conducting their research on fish, but the fishermen's contributions are usually not properly recorded and analyzed and are seldom acknowledged. After the research of Morril (1967), there have been many studies investigating the local ecological knowledge (LEK) that fishermen have about their fishing resources. This ever-growing literature indicate that fishermen's LEK may have the potential to improve fishery management, to the extent that the former can provide new information about the ecology, behavior and abundance trends of fish and other aquatic animals, about local ecological processes and their influences on fishing resources, among other topics (Johannes 1981; Marques 1991, 1995; Paz and Begossi 1996; Neis et al. 1999; Costa-Neto and Marques 2000; Johannes et al. 2000; Valbo-Jørgensen and Poulsen 2000; Saenz–Arroyo et al. 2005; Silvano and Begossi 2002, 2005; Silvano et al. 2006, 2007). Therefore, some researchers have claimed that fishery biologists would greatly benefit by including fishermen's LEK in their research and management initiatives (Johannes 1998; Haggan et al. 2003; Drew 2005), considering that such LEK is recorded, analyzed and interpreted in proper ways (Huntington 2000; Davis and Wagner 2003). Promising contributions of fishermen's LEK would be to help fishery scientists to formulate new research hypotheses (Silvano et al. 2006, 2007) or to improve sampling of biological data (Poizat and Baran 1997). Indeed, some interesting surveys adopted an integrated approach, by recording fishermen's LEK, deriving hypotheses based on it and testing such hypotheses through biological studies (Marques 1991; Poizat and Baran 1997; Aswani and Hamilton 2004). An alternative and simpler way to take advantage of fishermen's LEK in biological research would be through testing of hypotheses already presented in published ethoichthyological studies, or otherwise to formulate and test hypotheses based on available LEK data, but biologists have usually not been doing this.

Ethnoichthyological studies, such as those cited above, would obviously also bring potential benefits to the fishermen themselves, for example by strengthening their cultural values, giving them a greater political voice and recognition by managers, and improving dialogue between fishers and management agencies, among other advantages (Ruddle 1995; Berkes 1999). We will not be able to address these issues in detail here, although we recognize that such issues have the same level of importance as the application of fishermen's LEK in biological research. Our major aim is to undertake a brief review of published ethnoichthyological studies with a focus on coastal Brazilian fisheries and freshwater fisheries in both Brazil and Southeast Asia. We provide a series of hypotheses on fish ecology based on fishermen's LEK and compare them with what is already known from the biological literature. Our results may contribute to the so-called "data-less" fisheries management and research in the studied regions and other similar places, besides raising the interest of biologists to properly include fishermen's LEK when planning and conducting fisheries surveys.

2 Methods

We formulated a series of hypotheses on fish ecology based on a brief review of some published ethnoichthyological surveys conducted at the southeastern and northeastern coasts, a reservoir in the southeast and a large river in the Amazon Basin in Brazil (Silvano and Begossi 2002, 2005; Silvano et al. 2006, 2007), plus surveys held at the Mekong River, Southeast Asia (AMFC 1999). We focused on our own studies (Table 1), mostly because we better know the data, the fishing communities and the ecological realm, thus allowing us to better discuss the proposed hypotheses. We followed such biased approach for the sake of clarity and conciseness, not dismissing all other ethnoichthyological studies that had been made so far in other regions, such as the South Pacific (Johannes 1981; Johannes et al. 2000; Aswani and Hamilton 2004), North Atlantic (Huntington 1998; Berkes 1999; Neis et al. 1999; Davis and Wagner 2003), northeastern Brazilian coast (Cordell 1974; Marques 1991, 1995; Costa-Neto and Marques 2000), and other surveys from southeastern Brazilian coast (Paz and Begossi 1996; Begossi and Figueiredo 1995; Seixas and Begossi 2001).

2.1 Study regions and fishing communities

Below we provide a brief account of the regions and fishing communities addressed in this review (Table 1), more details can be found in the original studies.

The Piracicaba River in Southeastern Brazil is 115 km long, draining an urbanized region and receiving discharges of pollutants. In 1962, the lower Piracicaba River was dammed, forming the Barra Bonita Reservoir, which has small fishing villages along its banks (Silvano and Begossi 1998, 2001). Data presented here were obtained in an ethnoichthyological study held with peasant rural artisanal fishers (including five women) in two small fishing villages: Tanquã and Ponte de Santa Maria da Serra, inhabited by six and seven fisher families, respectively (Silvano and Begossi 2002).

The Negro River, located in the Central Amazon, and with a length of 1,700 km it is one of the main tributaries of the Amazon River. Waters of this river are acidic and show a low primary aquatic productivity, with few suspended sediments, and a surprisingly high fish diversity of more than 400 species (Goulding et al. 1988). The Amazonian rural inhabitants living along the banks of the Negro River, locally called *caboclos*, are descendants of native peoples and Portuguese and they derive their livelihoods mainly from fishing and

Table 1 Selected hypotheses on fish ecology based on data from fisher's local ecological knowledge in Brazil and Southeast Asia

Hypothesis	Fishing community	Region and country	Likelihood[a]	Comments
(1) The freshwater otter *Lutra longicaudis* regularly preys on fish in Piracicaba River.[b]	Rural artisanal fishermen	Piracicaba River and Barra Bonita reservoir, southeastern Brazil	Medium	Although *L. longicaudis* is piscivorous (Emmons 1990) and occurs in Piracicaba River region, it is surprising that populations of this otter should still exist there, considering that this river is suffering from severe habitat alterations, such as water pollution, deforestation and impoundment.
(2) The introduced piscivorous fish, *Plagioscion squamosissimus*, might be threatening native small characin fish in Barra Bonita reservoir.[b]	As above	As above	High	In accordance to data provided by fishers, a biological survey observed that *P. squamosissimus* preys on the small fish *Astyanax bimaculatus* (Braga 1995). Furthermore, fish landing data indicate that catches of these small characin fish had decreased from 1985 to 1994 (Silvano and Begossi 1998).
(3) At least two migratory fish species, *Prochilodus lineatus* and *Salminus maxillosus*, might be migrating and reproducing in Piracicaba River, in spite of the barrage located downstream.[b]	As above	As above	Medium	Both these species need to migrate upstream in order to reproduce (Vazzoler and Menezes 1992), but large dams usually disrupt the migratory movements and impair the reproduction of migratory fish (Petrere 1996). However, Piracicaba River has still about 100 km of free flowing river, both these fish species are relatively well represented in local fish landings, and the seasonal fisheries of these fish are consistent to seasonal migrations mentioned by fishers (Silvano and Begossi 2001, 2002).
(4) The piranha (*Serrasalmus spilopleura*) is a keystone predator, influencing a reservoir's fish community.[b]	As above	As above	High	Although we do not know the effects of piranhas on the fish community of the Piracicaba River, the former influences fish communities at the Pantanal wetlands, constraining the behavior, as well as the temporal and spatial distribution of many fish species (Sazima and Machado 1990). Furthermore, piranhas (*Serrasalmus* spp.) usually increase considerably in abundance after the formation of reservoirs, as these fish benefit from the lenthic environment and from the aquatic vegetation (Santos 1995; Sazima and Zamprogno 1985).

Table 1 continued

Hypothesis	Fishing community	Region and country	Likelihood[a]	Comments
(5) The Amazonian fish *Myleus rubripinnis* eats fruits of the floodplain forest plant *Margaritaria* sp. (Euphorbiaceae).[c]	Caboclos	Negro River, Brazilian Amazon Basin	High	Albeit such feeding habit has not previously been recorded in Negro River, this fish has been regarded as a fruit eater and a seed disperser of other plant species from Euphorbiaceae in Amazon (Goulding 1980).
(6) Juveniles (small individuals) of the *piranha*, *Serrasalmus gouldingi*, feed on detritus.[c]	As above	As above	Low	Both adults and juveniles of piranhas (*Serrasalmus* spp.) have been regarded as piscivorous, scale eaters, frugivores and cleaners of other fish (Goulding 1980; Sazima and Machado 1990), but not yet as detritivores. However, there are no data about feeding behavior of juveniles of *S. gouldingi* in Negro River, and detritus are an important food source for Amazonian fish communities (Knöppel 1970).
(7) The groupers (*Epinephelus* spp. and *Mycteroperca* spp.) spawn in their home reefs, instead of migrating to spawn in open ocean.[d, e]	Caiçaras and artisanal	Southeastern and northeastern Brazilian coast	Low	Groupers usually migrate to spawn in aggregations of many individuals in the open ocean, away from their home reefs, as have been recorded in Caribbean and in the Pacific (Sadovy 1996; Johannes 1981). Spawning aggregations of *Epinephelus itajara* were mentioned by spear fishermen at the South Brazilian coast (Gerhardinger et al. 2006), but the locations of these aggregations have not yet been determined for the grouper (*Epinephelus marginatus*) (Andrade et al. 2003). The reproductive behavior of Brazilian reef fish is still poorly known.
(8) The mullet (*tainha*) *Mugil platanus* enters coastal rivers to spawn.[d]	As above	As above	Low	Biologists argue that *M. platanus* spawns in open ocean during extensive migrations along the Brazilian coast, estuaries being a nursery ground for larvae and juveniles (Vieira and Scalabrin 1991; Romagosa et al. 2000). However, a single available mark recapture migratory survey on this fish was conducted about 40 years ago (Sadowski and Dias 1986), and spawning sites of this fish have not been recorded yet.

Table 1 continued

Hypothesis	Fishing community	Region and country	Likelihood[a]	Comments
(9) The sand drum (*corvina*) *Micropogonias furnieri* migrates between the open ocean and the shore, but does not undergoes extensive longitudinal migrations along the Brazilian coast.[d]	As above	As above	Medium	A study based on morphological similarity indicates that there are two distinct populations of this fish species, one in the south and other in the southeastern Brazilian coast (Vazzoler 1991), thus suggesting that this fish does not migrates over long distances. However, a more recent survey based on genetic similarity indicates that there would be only one population of this fish along the Brazilian coast (Levy et al. 1998). Nevertheless, because the migratory movements of this fish were not yet investigated at the Brazilian coast we do not know whether populations would be connected by migration of adults, dispersion of larvae or both.
(10) The snook (*robalo*), *Centropomus paralellus* spawns in estuaries or coastal rivers.[d]	As above	As above	High	Although the spawning behavior of this fish remains poorly known in Brazil, a recent biological study reports on the importance of estuaries as nursery grounds for *Centropomus undecimalis* in Puerto Rico (Aliaume et al. 2000).
(11) The bluefish, *Pomatomus saltatrix*, makes an extensive and regular seasonal migration along the Brazilian coast, from South to North, and closely following the schools of mullet (*Mugil platanus*), which migrates in the same way, but earlier.[d, e]	Caiçaras	Southeastern Brazilian coast	High	Despite the lack of surveys addressing the migratory behavior of *P. saltatrix* in Brazil, fishermen's information agree with the migratory pattern proposed by biologists: this fish moves against the prevailing maritime currents, which along the Brazilian southeastern coast flows from North to South (Haimovici and Krug 1996; Juanes et al. 1996).
(12) The large serranid fish, *Epinephelus itajara*, might be no longer an important predator of reef fish[e]	Caiçaras	Búzios Island, Southeastern Brazilian coast	Medium	Large serranid fish, such as *E. itajara*, are usually among the top predator in reefs, but populations of this fish have been severely decimated along the Brazilian coast (Gerhardinger et al. 2006). Furthermore, we do not know the extent of *E. itajara* predation pressure on other reef fish in Brazil.

Table 1 continued

Hypothesis	Fishing community	Region and country	Likelihood[a]	Comments
(13) Recreational divers using snorkels and spear guns to catch reef fish have been responsible for the decrease in the populations of target reef fish, such as the grouper, *Epinephelus marginatus* and the amberjack, *Seriola* spp.[e]	As above	As above	Medium	Although recreational divers may exert a pressure on reef fish, such pressure may be lower than those resulting from other fishing methods, because snorkeling is restricted by several constraints, such as divers' fitness, water visibility, bad weather and so on. However, the population of tourists may be several times larger than the population of the coastal cities surrounding the island during the summer, and many of these tourists may be diving to catch reef fish. Furthermore, we lack any survey or measure of the intensity of divers' recreational fishing activity at the southeastern Brazilian coast, and therefore the extent of the impact of such activity on reef fish remains an open question.
(14) *Aaptosyax grypus* is a pelagic species that migrates in December to February.[f]	Riverine artisanal fishermen, Mekong River[g]	Khong Chiam, Thailand	High	Rainboth (1996) states that *Aaptosyax grypus* is a fast swimming predator in upper and middle water. Roberts (1993) suggests that the species migrate for spawning purposes starting in late December.
(15) *M. erythrospila* migrates in big schools, and often together with other cyprinids and loaches (Cobitidae).[f]	As above	Mouang Khong (Laos and Khong Chiam (Thailand)	Medium	*M. erythrospila* is a migratory species (Warren et al. 1998), but almost nothing is known about its migrations (Roberts and Warren 1994).
(16) *Labeo chrysophekadion* migrates to small canals to go to rice fields and inundated grasslands for spawning in April–May.[f]	As above	Hong Ngu, Vietnam	High	This fish species has an important spawning ground in Bung Borapet swamp, in the Chao Phraya catchment in Thailand (Smith 1945).
(17) *Puntioplites falcifer* migrates to streams, canals and lakes during the flood season.[f]	As above	Sambor, Cambodia	Medium	Rainboth (1996), states that *P. falcifer* has a preference for large rivers and avoid standing water. However, Mattson et al. (2001) notes that *P. falcifer* dominates catches in Nam Ngum Reservoir, but that the species depends on the Nam Ngum River for recruitment.
(18) *Puntioplites falcifer* has a preference for deep pools or deep water in the river.[f]	As above	Cambodia, Laos, and Thailand	High	See above.

Table 1 continued

Hypothesis	Fishing community	Region and country	Likelihood[a]	Comments
(19) *Tenualosa thibeaudeaui* was much more common in the past.[f]	As above	Paksan, Laos	High	Roberts (1993) reported that this species was previously one of the most important species in the Khone Falls fisheries but it has undergone a drastic decline in recent years.
(20) *Hemibagrus filamentus* migrate from Mekong to small tributaries when water levels start to increase and flooding begins. It starts to occur in small streams around June.[f]	As above	Sung Kom, Thailand	High	Rainboth (1996) states that this fish moves into flooded forests to spawn and the young are usually first seen in August. In the Tonle Sap River (an important Mekong Tributary) maximum numbers of this fish are found as it returns to rivers in November and December.
(21) *Clarias batrachus* is much more common in floodplain lakes than in the main river.[f]	As above	Sambor, Cambodia	High	*Clarias batrachus* is found in standing or sluggish flowing water habitats, usually in floodplains and flooded forests (Rainboth 1996).
(22) *Clarias batrachus* migrate into small streams and into the rice fields and swamps when the level of the water is increasing.[f]	As above	Khanthaboury, Laos	Medium	See above.
(23) During the dry season, *Wallago attu* lives in deep water.[f]	As above	Laos and Cambodia	High	This fish is found in large rivers and can adapt to impoundments (Rainboth 1996).
(24) In June–July, groups of *Wallago attu* larger than 2 kg spawn in shallow water on flooded grassland. The eggs attach to the substrate and hatch within 3 days.[f]	As above	Chiang Saen, Thailand	High	*Wallago attu* spawns in inundated rice fields (Welcomme 1985).
(25) *Chitala blanchi* spends all the year in deep pools in the main river channel.[f]	As above	Phonthong and Khanthaboury, Laos	Medium	This fish is known only from the mainstream Mekong, at places with fast current and rocky substrate (Roberts 1993).
(26) *Chitala ornata* lays its eggs on submerged wood from April to May.[f]	As above	Laos and Thailand	High	This fish spawns on stumps or other solid objects in June (Rainboth 1996).
(27) *Chitala ornata* shows parental care: the female guards the fry.[f]	As above	Thailand and Cambodia	Low	The male of *C. ornata* guards the eggs (Smith 1945).

Table 1 continued

Hypothesis	Fishing community	Region and country	Likelihood[a]	Comments
(28) *Channa striata* spawns in the Mekong mainstream in May, in an area with sluggish water. The parent fish makes up the spawning ground and then guard for its young for about a month.[f]	As above	Khemaratch, Thailand	High	The nest of this fish is prepared in shallow water near the edge of a lake or a canal. The eggs are laid in a floating nest and are guarded by the male. Four days after hatching, the larvae can swim freely and after nine weeks it will seek towards the bottom and hide (Willey in Smith 1945).
(29) *Mastacembelus armatus* lives under rocks in the main river.[f]	As above	Mouang Khong, Phontong, and Huayxay, Laos	High	This fish is found along the bottom, over course substrates (Rainboth 1996).

More details on methods, data and number of fishermen who provided information to formulate these hypotheses are in the original sources, indicated in the footnotes along with the total number of fishers interviewed on each survey. Scientific names refer to fish species, unless otherwise stated

[a] Likelihood here refers to the degree to which the proposed hypotheses agreed with is already known from the scientific literature (for more explanations see text)

[b] 22 fishers interviewed, 17 men and five women, in two small fishing villages at the banks of the Piracicaba River and Barra Bonita reservoir (Silvano and Begossi 2002)

[c] 29 fishermen interviewed in the city of Barcelos, in the banks of Negro River (Silvano et al. 2007)

[d] 67 fishermen interviewed: 29 from the southeastern coast and 38 from the northeastern coast (Silvano et al. 2006)

[e] 39 fishermen interviewed in Búzios Island, southeastern coast (Silvano 2001; Silvano and Begossi 2005)

[f] 355 expert fishermen interviewed in Laos, Thailand, Cambodia and Vietnam (AMFC 1999)

[g] Data from the Mekong Basin are from several fishing communities along the Mekong River

from small-scale agriculture, such as growing cassava (Moran 1990; Silva 2003; Silva and Begossi 2004; Begossi et al. 2005). Results presented here come from a survey on ethnoichthyology of fishermen who have been living for many generations on Barcelos, a city in the Negro River margins (Silvano et al. 2007).

We also used data for a more extensive study on fishermen's LEK about reproduction of coastal fish, including seven artisanal fishing communities, four in the North of São Paulo State, southeastern Brazilian coast, and three in the North of Bahia State, northeastern Brazilian coast (Silvano et al. 2006). On the northeastern coast of Bahia, the artisanal fishermen exploit lobster, shrimp and fish, usually with small boats and using several types of fishing gear (Cordell 1974). Artisanal fishermen inhabiting the southeastern Brazilian coast are the caiçaras, who rely mostly on coastal fisheries as a source of food and cash and who descend from indigenous Brazilians and Portuguese colonizers (Begossi 1995; Diegues 1999). Fish is the main protein source for caiçara fishermen, who use gillnet and hook and line to catch fish, shrimps and squids (Begossi 1996). Additionally, we also used data from other studies held with caiçara fishermen from Búzios Island, located off the coast of São Paulo State, southeastern Brazilian coast (Silvano 2001; Silvano and Begossi 2005). The caiçara fishermen from this island rely mostly on fishing for cash and income (Begossi 1996), and possess detailed LEK about fish (Begossi and Figueiredo 1995).

With a total length of 4,880 km, the Mekong is the largest river in South-East Asia. The Mekong Basin, shared between six countries: China, Myanmar, Laos, Thailand, Cambodia and Vietnam, consists of 249 major sub-catchments, and drains a total area of 795.000 km^2 (MRC 1997). The Mekong River is extremely rich in fish species: The Mekong Fish Database currently counts 915 species distributed among 25 fish orders, 91 families and 360 genera (Visser et al. 2003). However, estimates of the total number of species ranges from 1,100 to more than 2,000, depending on the definition used for the boundaries of the basin. The Mekong River is heavily exploited for its fish, and the basin sustains one of the largest freshwater capture fisheries in the world with an annual fish harvest of 2.6 million tons (Van Zalinge et al. 2004). Most rural people in this region are rice farmers, however fish play an integrated part of peoples' livelihoods throughout the basin, as in most villages almost all households will to some degree depend on fishing. People are also highly knowledgeable about fish and it is common that even small children are able to identify close to 100 species of fish from photographs.

2.2 Data recording and analysis

Details on data collection and sampling varied slightly among surveys and could be found in the original sources. Basically, all the studies conducted followed the same general methodological approach: fishermen were interviewed through standardized structured questionnaires, containing questions about fish ecology, which were presented to all interviewees. Fish species addressed in these surveys were showed to interviewed fishermen as color photographs of recently caught and previously identified fish, following the same randomized order in every interview (Poulsen and Valbo-Jørgensen 1999; Valbo-Jørgensen and Poulsen 2000; Silvano 2001; Silvano and Begossi 2002, 2005; Silvano et al. 2006, 2007). The total numbers of fishers interviewed on each of these studies are in Table 1. Numbers of fishers who provided information that originate each hypothesis can be found on the original sources quoted above and in Table 1.

Regarding sampling of informants to be interviewed, usually fishermen were selected according to some specific and fixed criteria of age and fishing expertise. Following such criteria, interviewees were found based on advice of other fishermen, following the snowball method (Silvano et al. 2006, 2007). Exceptions to this approach were the smaller fishing communities at Búzios Island (Silvano 2001; Silvano and Begossi 2005) and at the Piracicaba River (Silvano and Begossi 2002), where all or most of resident fishers were interviewed.

In the Mekong study, a total of 355 expert fishermen were interviewed individually in 51 areas along 2,400 km of the Mekong in Laos, Thailand, Cambodia and Vietnam. The fishermen employed a total of 20 different mainly artisanal fishing gears. The fishermen were selected based on their responses in initial group interviews and the recommendations of other villagers. The interviewed fishers were all male and had from 2 to 60 years of fishing experience and were aged from 15 to 80 years (Valbo-Jørgensen and Poulsen 2000). All the interviews took place in small villages situated close to the Mekong mainstream. All interviews were carried out by staff from the respective Departments of Fisheries. Except for a few people from ethnic minorities, interviews were carried out in the fishers' own languages. The main focus of the study was to obtain detailed information on the migration and spawning habits of around 50 commercially important fish species, but fishermen also offered other information about the studied fishes (Poulsen and Valbo-Jørgensen 2000).

The hypotheses selected for discussion in this review (Table 1) are not a complete account of those that can be found in the original surveys. We rather choose to focus on a set of hypotheses that we judged would be more interesting and illustrative to a wider audience of biologists. Other researchers can identify more hypotheses in the original source material (and on other ethnoicthyological surveys not included in this review) or can even develop novel ideas based on the fishermen's LEK reported on in these surveys.

Besides clearly stating each hypothesis, we also compare it to what is already known about the subject according to the scientific biological literature. In the case of the Mekong study this proved to be very difficult, because the level of published information about most of the species is so limited and most information in the literature is actually based on local fishers' knowledge. But in some cases it has been possible to obtain information for the same fish species from other river basins. The recent taxonomic revisions of many of the most prominent fish species have further added to the difficulties when comparing with early literature on the subject. Usually, the comparison of LEK to the ichthyological literature renders three possible outcomes (Huntington et al. 2004a; Silvano et al. 2007): first, LEK and scientific data may agree with each other; second, there could be no scientific counterpart to be compared with LEK, thus the later consists in all that we know about that topic; and third, LEK may contradicts what is known by scientists. We illustrated these three circumstances using the item 'likelihood', an arbitrary measure of the extent to which a given hypothesis match what is already known in the literature (Table 1). As a general rule, we considered unexpected hypotheses, which contradict existing biological data, of low likelihood. Medium likelihood was assigned to novel hypotheses, which could not be properly compared to available scientific knowledge. Hypotheses that closely agree with scientific data were considered as being of high likelihood. However, it should be underlined that this classification does not reject the LEK: likelihood refers to the hypotheses, not to the fishermen's LEK on which they are based.

3 Results and discussion

We present and briefly discuss some hypotheses on fish ecology based on fisher's LEK from several regions from Brazil and Southeast Asia (Table 1). Such hypotheses were selected in order to include several distinct topics, such as migration, reproduction, feeding habits, abundance patterns, ecological relationships between fish and their predators, fishing pressure, among others (Table 1). We also present hypotheses ranging from high agreement to total disagreement with current scientific knowledge, reflected in the likelihood criteria (Table 1).

The likelihood of each hypothesis (Table 1) is intended to be an overall guideline for evaluation, but we believe that all the presented hypotheses, even the low likelihood ones, would be worth testing and could yield interesting biological data. The few studies that test biological hypotheses based on fishermen's LEK provide useful insights. The information gathered from fishermen on spatial and temporal fish distribution agrees with the results of an ichthyological survey in an African estuary: fishermen's LEK may therefore provide advice to improve sampling design of fish research (Poizat and Baran 1997). Guided by fishermen's information, Marques (1991) analyzes stomach contents of an estuarine catfish in a northeastern Brazilian estuary, and in agreement with what the fishermen said, he observes that this fish eats flying insects during a given month, a new biological data. In the Solomon Islands, South Pacific, Aswani and Hamilton (2004) investigate hypotheses based on fishermen's LEK about the distribution of adult and juveniles of a reef fish. Some of these hypotheses are corroborated by standard biological survey using underwater visual census, while others are not (Aswani and Hamilton 2004).

Considering our set of hypotheses (Table 1), when fishermen's LEK closely reflected what scientists already know (high likelihood), the former source of the knowledge reinforce the latter, at least on a local basis. Therefore, such hypotheses could be more easily corroborated through biological studies; for example, biologists could be following by telemetry some individuals of the Brazilian fish *Mugil platanus* and *Pomatomus saltatrix*: if marked fish move from South to North, then this hypothesis (Table 1) would be accepted. Similarly, through a brief survey of the stomach contents of some individuals of the fish *Myleus rubripinnis*, researchers could be confirming if this fish regularly eats fruits of the plant *Margaritaria* sp., as well as fruits from other plant species, in the floodplain forests of Negro River (Table 1). In the Mekong River, a study conducted during the spawning season of *Puntioplites falcifer* (Table 1) may reveal the size at sexual maturity for this fish, which is important information to proper fisheries management.

Alternatively, if doing such research is not feasible in the short term (as it is often the case), fishery managers may sometimes consider such high likelihood hypotheses (Table 1) to support management decisions even without testing, given their plausibility and concordance with scientific knowledge. Indeed, as observed by Poizat and Baran (1997), if scientists and fishermen, through distinct observations, mention the same pattern, it is probably close to the real pattern. For example, fishery managers in the Piracicaba River might seriously consider that the introduced Amazonian piscivorous fish, *Plagioscion squamosissimus*, had altered the native fish community through predation of small characin fish in a southeastern Brazilian reservoir (Table 1). Although the intensity of *P. squamosissimus* predation and its influence on native fish remains unknown in the Barra Bonita reservoir, introductions of piscivorous fish have seriously decimated populations of native prey fishes in other tropical freshwater ecosystems, such as the African lakes (Stiassny 1996). Furthermore, fish landings data indicate that *P. squamosissimus* had proliferated since its introduction in the Barra Bonita reservoir, while small characin fish decreased over the same time period (Silvano and Begossi 1998, 2001). Indeed, a dietary study confirms fishers' information that *P. squamosissimus* eats small characins in the Barra Bonita reservoir (Braga 1995). Therefore, this indicates that no further introductions of this or other piscivorous Amazonian fish should be attempted in southeastern Brazilian reservoirs. Also, the restrictions related to *P. squamosissimus* fishing could be relaxed, as an eventual depletion of this fish would not be harmful to the reservoir's fish community (Silvano and Begossi 2002).

Aaptosyax grypus is an extremely rare endemic fish in the Mekong Basin. The species was only described in 1991 and almost nothing is known about its biology: although it grows to a size of at least 100 cm (Rainboth 1996). This fish is so rare that it is unlikely that researchers would be capable of capturing even a single specimen during a relatively lengthy sampling program. Gathering knowledge from all the fishermen in the area where this fish is believed to exist (Table 1) is much more likely to provide basic information about this fish, and may also enhance the possibilities of biologists being able to obtain a specimen for study.

Discrepancies between fishermen's LEK and scientific studies may arise from their complementary characteristics: the former may be based on a long temporal series of observations sometimes transmitted over several generations as traditional knowledge grounded in a local realm, while the second assembles shorter temporal but more systematic observations rarely covering more than 2 or 3 years, but seeks generalizations on a broader spatial scale (Poizat and Baran 1997; Huntington et al. 2004b). Anyway, such differences might represent the best opportunities to find new biological data (Marques 1991; Johannes 1981; Johannes et al. 2000; Huntington et al. 2004a). Low likelihood hypotheses in our survey reflected such disagreement between fishermen's LEK and scientific knowledge (Table 1). However, testing such hypotheses may still yield new and unexpected scientific discoveries. For example, fishermen's LEK indicated that juveniles of the Amazonian fish, the *piranha (Serrasalmus gouldingi*) eats detritus, but such feeding behavior remains unreported for this fish species and for other *piranhas* (Serrasalminae) (Table 1). Therefore, testing such hypothesis may reveal a new feeding habit of this fish, but it is also possible that the fishermen were mistaken about this, confounding detritivory with necrophagy, which has been reported for other *piranha* species (Sazima and Machado 1990). Alternatively, detritus could be incidentally ingested by *S. gouldingi* when eating fruits, invertebrates or small fish hidden among the aquatic vegetation. At the Pantanal wetlands, Sazima and Machado (1990) report on the intake of plant material by *S. spilopleura* during scanning the vegetation in order to prey on aquatic invertebrates.

Another intriguing hypothesis refers to the possibility of adult individuals of the mullet (*Mugil platanus*) be entering coastal rivers and estuaries to spawn there during their extensive spawning migrations along the Brazilian coast (Table 1). Notwithstanding its low likelihood (according to scientists *M. platanus* spawns in the open ocean), perhaps such hypothesis deserves further investigation in order to be properly rejected, because exact spawning locations of this fish have not been found yet, some coastal fish populations may vary in their spawning behavior depending on location, and finding a new spawning site would be very important to the proper management of this commercial fish (Silvano et al. 2006). However, such hypothesis might also be based on an inaccurate LEK, for example because the fishermen confounded spawning and nursery grounds (Silvano et al. 2006), as estuaries are known nursery grounds for *M. platanus* in the Brazilian coast (Romagosa et al. 2000). In Mekong River, a fisherman's observation that the fish *Chitala ornata* shows parental care concurs with what is known from the literature (Table 1). However, according to the fisherman, it is the female that guards the eggs while the literature quotes the male (Smith 1945). In this situation it may be that the fishermen just assumes that the guarding fish is the female, and it would be necessary to ask him how he distinguishes males from females of this fish species.

Among the hypotheses of medium likelihood, the fishermen's LEK may be all we know about a particular biological aspect in a given location, and there is an excellent potential to make new discoveries (Table 1). For example, fisher's LEK in the Piracicaba River generated two interesting hypotheses: first, that we still find populations of freshwater otter preying on fish; and second, that two characin fish species, *Prochilodus lineatus* and *Salminus maxillosus*, would still be migrating and reproducing in the river, in spite of a large dam located downstream (Table 1). Large dams exert great impact on large migratory fishes by interrupting spawning runs often resulting in the reduction or extinction of fish populations (Barthem et al. 1991; Petrere 1996). However, two migratory characin fish, *P. lineatus* and *S. maxillosus*, are still relatively well represented in fish landings from Piracicaba River, the former being the most caught fish species (Silvano and Begossi 2001). The relative abundance of these fish actually increased in landings after the reservoir on the Piracicaba River was created (Silvano and Begossi 1998). This can be due to the fact that the two fish species are still able to migrate along the 100 km free flowing stretch of the Piracicaba River, or alternatively these fish might be spawning in tributaries of the Piracicaba River and Barra Bonita reservoir (Silvano and Begossi 2002). However, the exact reasons for the continued success of these species remain unknown. This issue would be worth investigating further, in order to mitigate and predict impacts of reservoir constructions on the aquatic habitats and fish communities (Santos 1995; Petrere 1996). Similarly, in Mekong River fishermen's LEK generated two interesting hypotheses. First, the fish *Wallago leeri* spawns in flooded grassland in July, at night. It also breeds in deeper water than the related *W. attu*. During the spawning performance the fish swim in pairs, and the eggs are spawned near the surface. Second, the fish *Puntioplites falcifer* attains sexual maturity when it weighs about 0.3–0.4 kg (AMFC 1999). Both these hypotheses are relevant to fisheries management, but there are currently no data from biological literature to assess the likelihood of these hypotheses, which possibly corresponds to all we know about such biological characteristics of these fishes.

4 Conclusions

The results of our review indicate that fishermen possess detailed knowledge about fish behavior and ecology and that this local knowledge can be recorded by researchers in a systematic manner, in order to be used to complement information from other sources or to formulate hypotheses that can be tested using more conventional research methodologies. In some cases there is close agreement between information derived from interviews and what has been published in scientific biological literature. In other situations results are pointing in opposite directions, there are many possible explanations for such divergence. Therefore, it should not automatically be assumed that it is the fishers that are wrong and the scientists are right. As with any other type of research it is necessary to try to explain why such contrasting conclusions have been reached, preferably by conducting new surveys, which will improve our understanding of fish ecology.

We are not aware of similar review surveys, addressing the formulation and testing of hypotheses based on local ecological knowledge of fishers or other local people in several distinct places. But there is an interesting comparison of traditional ecological knowledge (TEK) and the corresponding scientific interpretation about some ecological trends and patterns on the Artic ecosystems due to global warming (Huntington et al. 2004a, see comments below), which highlights the complementary nature of these two sources of knowledge. There are also some books gathering several surveys dealing with LEK and the management of natural resources (Dyer and McGoodwin 1994; Haggan et al. 2003). However, there are some interesting and detailed studies formulating and sometimes even testing specific hypotheses based on fishers' LEK. In a Brazilian lagoon, Marques (1991) formulates the hypothesis that an estuarine catfish would be eating terrestrial insects during a given season, based on fishers' knowledge. This author has tested and corroborated such hypothesis through s survey of fish diet, thus recording a new and unusual food chain in Brazilian estuaries (Marques 1991). In a coral reef lagoon system of the Solomon Islands, South Pacific, Aswani and Hamilton (2004) proposed four hypotheses regarding the ecology and fisheries of a threatened reef fish (*Bolpometodon muricatum*) based on fishermen's LEK. These hypotheses were checked through biological and fisheries research and three were confirmed, about the best fishing grounds and habitats of adults and juveniles, and one was rejected, about lunar periodicity and fish catches (Aswani and Hamilton 2004). Sarda and Maynou (1998) proposed and tested three hypotheses to explain the common held perception among Spanish fishermen in the Mediterranean coast that shrimp catches increase on Fridays. Analyses of fish landings data confirmed two of the three hypotheses: that fishermen remove competitors from the fishing grounds more intensely than shrimp along the week and that shrimp attain higher prices towards the end of the week, thus driving fishermen to catch more shrimp on Fridays (Sarda and Maynou 1998). In a recent article, Johannes et al. (2000) discuss five examples where data based on fishers' LEK are in disagreement of those from biologists, but the former are more accurate to local management of fish and whales. In one of these examples, biologists concluded that bait fishing in a Pacific Island would not be affecting local fisheries, as target fish would not be feeding on baitfish, contrarily to fishermen's claims. However, subsequent and more detailed biological and fisheries surveys indicate that the former biological studies had underestimated the catches of baitfish predators by local fishermen, who are possibly right regarding the impacts of bait fishing (Johannes et al. 2000). Finally, in a survey comparing scientists and local people's perceptions on the impacts of global warming on Artic ecosystems, Huntington et al. (2004a) observed that these two groups may show distinct perceptions of the same ecological phenomenon. For example, people believe that warm summers prejudice the cloudberry (*Rubus chamaemorus*) fruit production, while scientists did not notice any changes in flowering of this plant during this season. Such different view is because the former are dealing with fruit production (which is used as food), while the second analyzed reproductive output (Huntington et al. 2004a). All these examples reinforce the main conclusion from our review: that fishermen's LEK is a useful source of information, which need to be verified and improved by conventional biological research whenever possible.

In this paper we have demonstrated the value and usefulness of fishermen's LEK to fisheries research. Indeed, in many tropical developing countries, such as Brazil and Southeast Asia, where species diversity is high, fisheries are complex and funds for carrying out biological research are very limited, information provided by fishers may be the only data at hand. In this situation, fishers' based data may be particularly useful to focus research through the formulation of testable hypotheses, besides providing useful information, as proposed by Johannes (1998) as a 'data less' approach to fisheries management. Such an approach would use all the scarce data from conventional sources, plus non-conventional information based on fishers' knowledge (Johannes 1998). The kind of information and the level of detail needed to improve fisheries management will depend on the exploited species, the types of fisheries in concern and the local situation. There is no single right answer, which may be applied universally. Management building on and integrating the knowledge and traditions of local people, is therefore much more likely to be successful than rules and regulations imposed by a central administration. A first and necessary step to foster fishermen's participation in management would be to properly record, analyze and interpret LEK, in a manner that is acceptable to fisheries managers (Davis and Wagner 2003). We hope that our analysis will contribute to achieve the rightful placement of fishermen's LEK in fishery science and management as advocated by Dyer and McGoodwin (1994), Johannes (1998), Berkes (1999), Haggan et al. (2003) and Drew (2005).

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