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Last Trip Return Rate Influence Patch Choice Decisions of Small-Scale Shrimp Trawlers: Optimal Foraging in São Francisco, Coastal Brazil

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Abstract Studies using Optimal Foraging Theory to understand human behavior have stated that daily variation in patch profitability could explain mismatches between theoretical predictions and actual behavior. In this paper, we tested whether the return rate of the last fishing trip could predict fishers' choices to return or choose a different fishing ground for their next trip. We collected data on fishing trips using interviews and direct observation of fishers' activities at the main landing point in São Francisco, a small-scale shrimp fishing community on Brazil's southern coast. We found that fishers returned more often to fishing grounds where the return rate of the previous fishing trip was above the average gross return of the environment. Daily variations in patch quality accounted for fishers' decisions, but other factors may also influence the observed behavior, such as scale of analysis, information exchange, environmental conditions, and economic variables.

Keywords Optimal Foraging Theory · Small-scale shrimp fisheries · Patch choice decision · Central Place Foraging · Human ecology

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Introduction

Many authors have stated that the study of fishers' behavior is an essential step to understand decision-making processes regarding the use and management of natural resources (Hilborn 1985; Aswani 1998a, b; Béné and Tewfik 2001; Begossi 2008). However, the literature is still limited on this topic, mainly for small-scale fisheries (Salas and Gaertner 2004). Since the beginning of the 1980s Optimal Foraging Theory (OFT) has been used to understand decision-making processes regarding food acquisition among hunter-gatherer societies (Kaplan and Hill 1992, for a revision), but to date few studies have used the models derived from this theory to understand fishers' behavior (but see Beckerman 1983; Begossi 1992; Aswani 1998a, b; Seixas and Begossi 2000; Sosis 2002; Begossi *et al*. 2005; Begossi *et al*. 2009). In this paper we use OFT to understand decision-making processes concerning a group of small-scale shrimp trawlers in São Francisco, within the municipality of São Sebastião on the southern coast of Brazil.

OFT is a corpus of formal theoretical models used to investigate, for example, which food items an individual should consume (Prey Choice Model), where to search for those items (Patch Choice Model), how long to search for them (Marginal Value Theorem), how many items should be brought given the distance traveled (Central Place Foraging), among others (MacArthur and Pianka 1966; Charnov 1976; Orians and Pearson 1979). The basic assumption of these models is that maximizing the rate of nutrient acquisition enhances an individual's fitness (Bird and O'Connell 2006). Therefore, if an animal can acquire food in a more economical way, given some currency (e.g., calories, protein, money), efficient foraging behavior can be favored by Darwinian natural selection (MacArthur and Pianka 1966; Kaplan and Hill 1992).

Some of these classical models have been applied to understand fishers' behavior. For example, Begossi (1992) used the Marginal Value Theorem (MVT; Charnov 1976) to predict how long fishers should stay in a fishing ground. In general, shrimp fishers remained in the fishing ground longer than was expected by the model. Other studies found that, although human foragers more frequently exploited the most profitable patches (aggregations of resource items in the environment, such as fishing schools), they did not exploit them exclusively (Beckerman 1983; O'Connell and Hawkes 1984; Smith 1991). A frequently cited *ad hoc* explanation for this observation is that daily fluctuations in patch quality might explain such deviations from the expected behavior (Kaplan and Hill 1992; Sosis 2002). Few studies, however have addressed this question.

In this study, we will focus our analysis on two kinds of decisions abstracted from fishing activity. Firstly, the main decision that precedes the trip, which is (1) where the fisher should go fishing on that day. Secondly, the decision made during the trip, namely (2) how long a fisher should stay in the chosen fishing ground once s/he has traveled to it.

There is evidence that the first kind of decision may be influenced by information acquired on previous captures. For example, Sosis (2002) found that Ifaluk fishers of Micronesia exploited alternative fishing grounds when the return rate of the previous day (or previous morning) was below the overall per capita return rate of alternative fishing grounds. Similarly, Eales and Wilen (1986) studied the pink shrimp fisheries on the coast of California and found that fishers are influenced by the information about relative abundance from the previous day. Based on these studies, it is reasonable to expect similar behavior in the case of the shrimp trawlers in São Francisco. The Patch Choice Model offers a framework to analyze this problem. According to this model, a forager (in this case, fishers) should remain exploiting a patch as long as the instant return rate of that patch is higher than the average return rate of all patches within a certain bounded area (Marginal Value Theorem; Charnov 1976).

The second kind of decision fishers face (namely how long should a fisher stay on the chosen patch), after they have decided on and traveled to the fishing ground, can be evaluated through the Central Place Foraging (CPF) model (Orians and Pearson 1979). This model is used to understand the foraging behavior of individuals who return to a central place to consume their prey. Humans generally return to a central place after a foraging expedition, and this is especially true for fishers, which makes CPF a model often used in fisheries (Begossi 1992; Bird and Bliege Bird 1997; Seixas and Begossi 2000; Begossi *et al.* 2005; Begossi 2008; Lopes 2008b; Begossi *et al.* 2009). According to Orians and Pearson (1979), CPF models have three basic units: an outbound trip, a foraging period, and a return trip. Energy is expended in all three phases, but acquired only in the second, so the forager tries to compensate the costs of the first and third phases during the foraging period. Then, assuming that costs of travel increase with distance to the patch, general predictions of the CPF model are: 1) time searching inside the patch (foraging period) increases with distance to the central place, and similarly, 2) optimal load size increases with the distance to the patch in relation to the central place.

Based on the OFT models reviewed, and assuming that fishing grounds are patches of resources, we make three predictions about fishers' behavior:

P_1: Fishers will return to a given fishing ground if, in the previous trip to that location, their gross return rate (R$\$*hour^{-1}man^{-1}$, where R$ is Brazilian Real) was above the gross return rate of the environment; otherwise, they would rather change fishing grounds.

P_2: Fishers will compensate their expenses by fishing for longer periods when traveling to more distant fishing spots; in statistical terms, we expect a positive correlation between the trawling time and the travel time (to and from the fishing spot).

P_3: Fishers will bring more catch when they travel to distant fishing grounds, or in statistical terms, the return will be higher (money and catch) when the travel time to the fishing ground is longer.

Methods

Study Area

The northern coast of São Paulo State is 161 km long and is composed of 164 beaches and 17 islands. The northern portion of this coast encompasses the municipalities of Ubatuba, Caraguatatuba, São Sebastião and Ilhabela (Souza and Begossi 2007). São Sebastião (23°42′18″ to 23°45′38″ S–45°25′41″ to 45°53′49″W) is composed of a narrow lowland area between the sea and the slopes of the Atlantic Forest and is inhabited by almost 70,000 persons (IBGE 2000). The climate of the region is temperate with dry winters and hot summers (Peel *et al.* 2007). The average annual temperature is 24.8°C (Cepagri 2009). The study was carried out in the neighborhood of São Francisco, a small-scale fisheries community (Fig. 1).

Similar to other communities along the southeastern coast of Brazil, São Francisco is home to a *Caiçara* community. Caiçara is a mixed-heritage group from Portuguese colonists, native inhabitants, and Africans, whose livelihoods depend on small-scale fisheries, small-scale agriculture, and an increasing income from tourism

Fig. 1 Fishing spots used more than three times during the study by shrimp fishers from São Francisco (São Sebastião-SP). Black ellipses represent the fishing spots whose names are close to them. Number of fishing events in each spot is shown inside parenthesis. São Sebastião, Ilhabela and Caraguatatuba are the three municipalities that encompass the whole fishing area used by shrimp fishers of São Francisco neighborhood. Other fishing spots used: three events: Farol do Boi, Pacuíba, and Pirabura; two events: Barequeçaba, and Boracéia; one single event: Palmeiras, Poço, Ponta do Arpoá, São Lourenço, and Serra da Ilha

and non-timber forest products (Hanazaki *et al*. 2007; Diegues 2008). Based on the number of boats and dugout canoes in the area, we estimated the number of fishers in São Francisco at 86.

Data Collection

Fishing landings were sampled during 22 consecutive days (from April 16 to May 7, 2008) at the *Cooperpescass*[1] in São Francisco. Interviews were conducted using closed-ended questionnaires when catch landings were weighed. We selected fishers who were over 20 years old; had more than 10 years of experience fishing in the area; were active during the research period; and were willing to participate in the study. In total, 20 fishers participated in the study. The first time a fisher was approached, the objectives of the study were explained, and only fishers who agreed to participate in the study had their landings registered. Specific data about the boat and fisher were also obtained in this first approach, such as boat length and type, number and size of trawl-nets, fisher's age, fishing time (number of years working as fisher), and if s/he fished part- or full-time, where full-time means that the fisher does not have other jobs besides fishing. The size of the try-net (a kind of sampling trawl net) was not asked directly of fishers. We had the opportunity to observe one of those nets during repair process and its head rope length was approximately 4 m.

During the fishing landings, fishers were asked about their departure time, travel time to the fishing spot, name of the fishing ground(s) used, number of trawls, time spent in each trawl, and number of crew members. Arrival time was registered as the time when fishers anchored their boats. Catches were separated according to selling categories (see Table 1), and weight was registered directly from a scale with a precision of 0.5 kg for all catch categories except for white shrimp, for which the scale precision was 0.1 kg. Species identification of the selling categories was based on Graça Lopes *et al*. (2002); Lopes (2008a) and Palomares and Pauly (2009).

During the interviews, fishing grounds were identified by the names used by fishers, and the location of these grounds was then determined using a satellite image of the region with the help of an experienced fisher (who fished in the area for more than 20 years, and was acknowledged as an "expert" shrimp fisher by the other fishers). This process was carried out at the end of the data collection period, to ensure that all fishing grounds mentioned in interviews were located. The printed image was brought to the fishing landing point and we asked the fisher to indicate the position of all the fishing grounds we had in our list. Other fishers who were observing the process eventually got involved in the process and confirmed the spots mentioned by the expert fisher. This process of mapping fishing grounds is similar to those used by Seixas and Berkes (2004). For clarity of the image, Fig. 1 shows only most frequently used (more than three times) fishing grounds.

Statistical Analysis

The statistical analysis used in the study consists of two simple tests: chi-squared tests and simple linear regressions. To test the first prediction (P_1; where fishers decision to go fishing is based on the gross rate of capture of the previous

[1] Cooperpescass—Fisheries Cooperative São Sebastião (23°45′22″ S–45°24′40″W)—a fish and shrimp processing plant where fishers sell their catches and buy diesel and ice to store their captures. In this work, Cooperpescass is the fishing landing point (central place).

Table 1 Total catches registered by species in fishing landings (N=77 shrimp fishing trips). Selling prices paid to fishermen for each species is converted in US$ (US$ 1=R$ 1.67, average between 04/16 and 05/07 of 2008). The percentage relative to total catches of each species is represented in the column (%)

Common name	Species	Family	Price/Kg (US$)	%	Total catches (Kg)
Shrimp					
Sea bob shrimp	*Xiphopenaeus kroyeri*	Penaeidae	3.29	42.90	2903.00
White shrimp	*Litopenaeus schmitti*	Penaeidae	7.19	21.41	1448.65
Argentine red shrimp	*Pleoticus müelleri*	Solenoceridae	1.80	9.24	625.00
Argentine stiletto shrimp	*Artemesia longinaris*	Penaeidae	1.50	2.50	169.00
Total (shrimp)				76.04	5145.65
Fish					
Mixing of small fishes (bycatch)	–	various	0.60	18.22	1233.00
Brazilian codling	*Urophycis* spp.	Phycidae	1.50	3.40	230.00
Ray	–	–	1.20	1.29	87.50
Southern Weakfish	*Cynoscion jamaicensis*	Sciaenidae	1.50	0.41	28.00
Weakfish (pescada)	*Cynoscion* spp.	Sciaenidae	3.59	0.36	24.30
Southern kingcroaker	*Menticirrhus americanus*	Sciaenidae	0.60	0.10	7.00
Whitemouth croaker	*Micropogonias furnieri*	Sciaenidae	1.20	0.01	1.00
Total (fish)				23.80	1610.80
Other groups					
Crab		Portunidae	1.80	0.14	9.50
Octopus		Octopodidae	4.19	0.01	0.81
Total (other groups)				0.15	10.31
Total				100.00	6766.76

Identifications were based on: Fishbase (http://www.fishbase.org/), Sealife base (http://www.sealifebase.org/), and Graça Lopes *et al*. (2002). Although the common names are used to separate commercial categories, it is possible that accurate identifications could reveal even more species grouped under the same common name as observed in the case of the sea bob shrimp by D'Incao *et al*. (2002, pers. obs.)

day), we performed a chi-square test. We designated the threshold for this decision as the average gross return rate of the environment, which was calculated using the data from all the 77 fishing trips surveyed, according to the following formula:

$$A = (R/T)/N,$$

where: A is the average gross return rate; R is the monetary return in Brazilian *Reals* (R$; US$ 1=R$ 1.67, average between April 16th and May 7th 2008); T is the round trip time in hours; and N is the crew number. Although we used the whole data set to calculate the average return rate, the test itself was conducted with data from 49 fishing trips, because for 28 of the fishing trips we could not register accurate information on the previous trip's fishing ground.

Simple linear regressions were used to test the hypothesis concerning the trade-offs involved in the travel time to the fishing spot, trawling time (both variables in minutes) and the return obtained (in kg and R$), namely predictions P_2 and P_3. In cases when fishers visited more than one fishing ground within a single trip, we considered the travel time to the first fishing ground if fishing grounds were contiguous to each other (adjacent beaches, for example *Martim de Sá* and *Enseada*—Fig. 1). We excluded from our regression analysis fishing trips when the different fishing grounds were far from each other, for example when the first fishing ground was *Martim de Sá* and the second one, *Guaecá* (Fig. 1), since we did not register the travel time between them.

All data used in linear regressions were normalized using natural logarithm (Ln) transformations. For P_2, travel time (to and from the fishing spot) was used as the independent variable and trawling time as the dependent variable to test if travel time could explain the amount of time fishers spent trawling. For P_3, we used travel time (to and from the fishing ground) as the independent variable and gross financial return (R$) and catches (kg) as dependent variables. Because linear regression analysis only considers independent events, we used data on only one fishing trip of each fisher (boat). To do so, we selected from our total sample the first fishing trip sampled from that fisher (boat). Therefore, for predictions P_2 and P_3, the number of events (n) is 17 fishing trips. In order to avoid type I and type II errors in hypothesis testing, we used Bonferroni correction to adjust alpha level. Alpha values (α) for the regressions are shown in Table 3. For prediction P_3 we tested the returns (monetary and catch) first for the whole set of species caught (total catch), and later the returns from the shrimp caught separately. We tested shrimp returns separately because shrimp is the target species.

Results

Characterization of the Trawling Activity in São Francisco

Fishing activities of 20 fishers (17 boats) were registered during the study. On average, the shrimp fishing trips departed at 4:20 AM and returned at 2:30 PM, although some trips took more than 24 h. Each trip was performed by one or two fishers, generally the boat owner alone or the boat owner with one helper. The average age of the interviewed fishers was 41.2 years (min=32; max=53; N=20), and the period of time they had dedicated to fisheries ranged from 12 to 42 years, with an average of 28.4 years. Only one was a part-time fisher; all others reported being full-time fishers.

There are three main types of motorized boats used for shrimp fisheries in São Francisco, called *bateira*, *baleeira* and *bote*. All three kinds of boats are relatively small, with an average length of 9.97 m (min=7.7 m; max=18.5 m; SD=3.00; N=17) with small variation due primarily to shape of the boats' stern. Boats have been adapted to the outrigger trawling method, in which two lateral structures, the outriggers (*tangones*), support one trawling net on each side of the boat (FAO 2004). The head rope length of each trawl net was 12.96 m, on average (min=5 m; max=22; SD=4.19), and they work by dragging on the sandy bottom of the sea. In some boats, fishers use one additional trawl net called a "try-net", which is rigged manually. This is a miniature trawl net which is used to sample the fishing spot at the beginning of the trawling activity.

We classified the shrimp fishery in São Francisco as a small-scale trawling activity because when we compare this fishery to large-scale trawlers we can observe: 1) smaller average boat size; 2) relatively lower catch; 3) fishers are the boat owners and fishery is part of their livelihood strategy (they do not work for a larger company, for instance); and 4) although boats may have VHS radio and GPS devices, they do not have sonar, which is a device commonly found in large-scale fishing vessels (comparison based on FAO 2005).

A total of 6,766.8 kg of fish and seafood were landed at the São Francisco landing point (Table 1). Shrimp represented 76% (5.1 tons) of the total landed, while 23.8% (1.6 tons) were fish and 0.1% represented other organisms (mainly crab and octopus). For the shrimp catches, the main species landed were the target species, sea bob shrimp (*Xiphopenaeus kroyeri*) and white shrimp (*Litopenaeus schmitti*), and the two combined represented approximately 64% of all landings. Most fish landed were by-catch (defined here as catch which is not the target species), and included demersal fish, such as *Menticirrhus americanus, Cynoscion jamaicensis* and *Paralonchurus brasiliensis,* or some small individuals of *Trichiurus lepturus* and *Micropogonias furnieri* (see Table 1 for common names of fishes). Landed by-catch accounted for 18.2% of total catches. Generally, when fishers landed small quantities of by-catch, it was all donated to poor people who helped fishers during landings; however, when the quantities landed were higher (>20 kg), it was sold to Cooperpescass at a very low price (approximately US$0.45/kg, on average).

Figure 1 shows the map of the study region and the fishing spots used more than three times during the study. In total, 19 fishing spots were used, but only nine were used more than three times. Fishing trips data are shown in Table 2.

Optimal Foraging Models Predicting Fishers' Behavior

Figure 2 shows the results for the first prediction of this paper (P_1). For 49 fishing trips, when the mean gross return rate (R\$ hour^{-1} man^{-1}) of a fishing ground on the previous trip was below the mean gross return rate of the environment (the threshold value R\$16.44 h^{-1}man^{-1}), trawlers changed fishing grounds for the following trip

Table 2 Shrimp fishing trips. Average, Standard Deviation (SD) and Minimum (Min) and Maximum (Max) values for fishing trips data. *N*=77 fishing trips

	Travel time (min)	Total trip time (min)	Fishing time (min)	Number of trawls	Time of each trawl (min)	Total trawl time (min)	Gross return (Kg)	Gross return (U$)
Average	93.90	1,228.60	1,040.81	5.79	107.40	628.97	87.88	293.22
SD	60.06	1,000.56	941.35	3.96	22.42	513.92	90.42	327.94
Min	15.00	340.00	240.00	2.00	60.00	180.00	7.00	23.05
Max	360.00	6,720.00	6,420.00	25.00	150.00	3,750.00	515.00	1,977.84

Total trip time is the total amount of time spent from the very moment of the departure until the arriving. Fishing time is the total trip time minus the travel time multiplied by 2 (travel to and from the fishing spot).

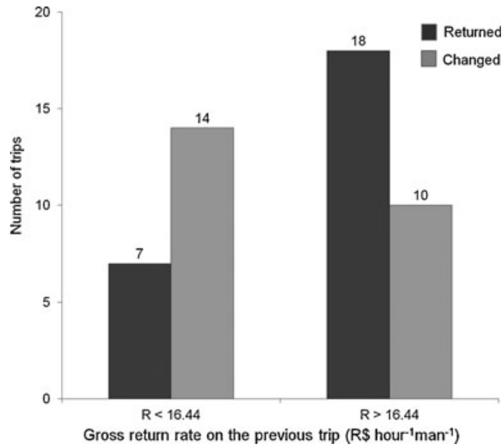

Fig. 2 Number of fishing trips in which fishers returned to (dark gray bars) or changed (light gray bars) the fishing spot based on the previous capture. In the first situation, gross return rate was below the average return rate of all spots in the environment (R $16.44 man^{-1} h^{-1}). In the second situation, gross return rate of the fishing spot on the previous day was above this threshold. (χ^2=4.7; p<0.05; n=49; df=1)

more frequently than returning to the same place. On the other hand, when the gross return rate of the fishing ground on the previous trip was above the threshold, trawlers returned to that fishing spot more often than changing locations (χ^2=4.7; p<0.05; n=49; df=1).

The results shown in Table 3 confirm the second and third predictions (P_2 and P_3) of the paper. Time spent trawling is positively related to travel time. Other variables being equal, 33.9% of the variation in time spent trawling can be explained by the travel time. Consequently, the longer fishers take to reach the fishing ground, the larger the catches they bring to the central place (fishing landing point). Other variables being equal, 45.4% of the variation of total catches is explained by the variation in travel time. When we considered only the target species (shrimp), 54.6% of the variation in catch is explained by travel time (Table 3).

Consequently, the further fishers travel, the more money they earn. For example, 51.2% and 53.2% of the variation in monetary returns, respectively to total catch and target species catch, is explained by the variation in travel time (Table 3). While financial return fits the model better than biomass (kg) for total catch, biomass is more correlated to travel time than financial return when we consider only target species.

Discussion

Decision-making in fisheries is a complex phenomenon and might be analyzed using different approaches. For example, Durrenberger and Pálsson (1986) argued that it is important to differentiate between cognitive and behavioral decision-making processes involved in fisheries. According to these authors, to study the cognitive decision-making processes, one would need to take into account the day-to-day activities and the cultural context in which decisions take place. In this regard, some authors have stated that more holistic approaches are necessary to understand the complex process of decision-making in fisheries (Béné and Tewfik 2001). In our study, on the contrary, the OFT approach provided a framework to study behavior by testing the variables defined *a priori*, from an etic (outsider) point of view (see Harris (1976) for etic/emic distinction). This approach was used because we aimed at understanding general patterns in behavior, although we are aware that by doing so, we may lose details of the studied phenomena. We believe that OFT provides an interesting null hypothesis to discuss deviations from the observed phenomena, when compared to the expected behavior.

By testing hypotheses about fishers' behavior based on OFT, we were able to identify important variables involved in two different decisions regarding fishing activities. In the first type of decision, which is the choice of the fishing ground, fishers responded individually to daily variations in patch quality. Fishers avoided low catches (and monetary returns) by returning more often to fishing grounds where their returns on the previous trip were higher than the average of the environment, which is consistent with the findings of

Table 3 Linear regressions carried out with fishing landings data. Time (min) and return data (in Kg or R$) were normalized through Log_n transformations. Trawl.time = total trawling time; Tr.time = travel time; Ret (Kg) = gross return in Kg; Ret ($) = gross monetary return; X = independent variable; Y = dependent variable; N=17 shrimp fishing trips. Alpha level for each test after Bonferroni correction is shown in the column "α". In the last column, T = analysis performed considering total catches, and S = analysis considering only shrimp catches

Prediction	Regression (Y, X)	Equation (Y = a + bX)	r^2 (%)	*P*	*Df*	α	T/S
P_2	Trawl.time, Tr.time	Y = 2.3080 + 0.7827X	33.9	0.0135	16	0.015	–
P_3	Ret (Kg), Tr.time	Y = −3.1468 + 1.4124X	45.4	0.0033	16	0.019	T
P_3	Ret (Kg), Tr.time	Y = −4.4389 + 1.5971X	54.6	0.0010	16	0.014	S
P_3	Ret ($), Tr.time	Y = −2.4575 + 1.5976X	51.2	0.0015	16	0.021	T
P_3	Ret ($), Tr.time	Y = −2.8009 + 1.6502X	53.2	0.0012	16	0.013	S

other studies (Sosis 2002; Eales and Wilen 1986). These results help to explain why foragers may not exploit the most profitable patches exclusively, as was observed in other studies (e.g., Beckerman 1983; O'Connell and Hawkes 1984; Smith 1991). The ranking of patches according to their profitability must take into consideration the dynamic variations on patch quality at different scales of time.

In the second type of decision, concerning the distance to fishing grounds, the further fishers travel, the longer the time they spend fishing and, consequently, the higher the returns they bring to the central place, which was also observed in other studies (Begossi *et al*. 2005; Lopes 2008b; Begossi *et al*. 2009). The positive relationship between return (either biomass or monetary) and travel time is even higher when only the target species (sea bob shrimp and white shrimp) are considered (Table 3). This result indicates that fishers are bringing more higher-priced species when they travel further. Even though one may think that this may simply represent overfishing close to the village studied (since fishers travel to other beaches and not to deeper areas of the ocean, because target species live in shallower waters), trawling activity is widespread in the area. Therefore, the other beaches are expected to be overfished as well.

Although the variables used (gross return rate of the previous trip and travel time) explain part of the variance in the observed behavior, it is interesting that these variables do not entirely account for the observed behavior. With regard to this problem, there are additional variables that might help us to analyze our results, such as scale of analysis, daily variation of environmental conditions, information exchange among individuals, and economic processes.

The scale of analysis is one factor that may influence results related to foraging behavior. The time scale used in this study, focusing on daily activities, is generally neglected in other studies on fisheries, which prioritize seasonal comparisons (e.g., Durrenberger and Pálsson 1986; Eales and Wilen 1986; Bené 1996; Lopes 2008b). Although new insights can be gained by analyzing variations within a smaller time scale (e.g., Sosis 2002), this approach can also overlook important seasonal variations on behavior. For example, Lopes (2008b) studied the fisheries in Guarujá (southern coast of Brazil). She gathered landing data from gillnet and trawling fisheries during the whole year. When the whole dataset was used, little correlation was found between trawling time and shrimp caught. Nevertheless, when seasonal data were used, stronger correlations were observed. Moreover, Bené (1996) studied the French Guyana shrimp fisheries and observed that the seasonal changes in fleet distribution were caused by market constraints. Such results suggest that our conclusions may be limited by the scale at which the study was conducted (within 22 consecutive days). We suggest that future research should focus on the influence of different time scales on the study of behavior.

In addition to the time scale, the geographic scale seems to be an important factor shaping fishers' behavior. Eales and Wilen (1986) also studied the influence of previous captures on the choice of fishing grounds. They verified that when macro and micro geographic regions were compared, the former areas confirmed predictions about patch quality influencing daily decisions more accurately. In our study, we considered the fishing ground as the spatial scale for decision-making, but a larger geographic scale of analysis could provide different results.

Along with scale of analysis, environmental conditions play an important role on decision-making. For example, climate and tide conditions may influence prey distribution or the decision not to travel to a further fishing ground if a storm is imminent (Durrenberger and Pálsson 1986). Prey characteristics, such as mobility, were also indicated by Begossi (1992) and Begossi *et al.* (2005). Begossi and colleagues (2009) also stressed that the unpredictability and non-visibility of fish resources make the extractive systems of artisanal fishing an activity based on "rules-of-thumb", probably based on previous experiences. In the face of all of these variables, the gross return rate of the previous trip alone was a good predictor of the trawler's decision to return to or changing the fishing ground.

The perception about the actual richness of the patch is another variable that may influence foraging behavior (Dreyfus-Leon and Gaertner 2006). Some fishers from São Francisco use a try-net, a kind of sampling net, in addition to the main trawl net when they arrive at the fishing ground. The try-net, a miniature of the main trawl net, is launched at the beginning of the trawling, and after 20–30 min the fishers haul it. The catch in the try-net is an indicator of what is being caught in the main trawl net. If the catches in the try-net are good, the fisher remains on that fishing ground; otherwise, s/he should look for another. If s/he does not use the try-net, s/he has to wait for approximately 1 h 40 min (average time of one trawl, Table 2) to sample the fishing ground. This strategy helps the fisher acquire information on the fishing ground faster, thereby enhancing his/her efficiency.

Information exchange among fishers can also explain deviations from the OFT models. In this work we assessed decisions based only on individual information (fishers returning to or changing the fishing grounds according to their own previous experiences), but we observed at least one situation in which the decision was probably based on *other* fishers' past experiences. For example, we observed a situation when a fisher coming from Guaecá (Fig. 2) landed a very large catch of white shrimp (about 252 kg). On the following day, seven boats went to that same fishing ground (Guaecá), while only three fishers decided to go to another. Similarly, Durrenberger and Pálsson observed that skippers usually follow "famous fellow skippers" (Durrenberger and Pálsson 1986:221), who are known for their successful results. We can even think that in this case, the landing point at São Francisco may be functioning as an "information-center" where observers acquire information about patch quality from demonstrators, as observed in other mammalian aggregations (Galef and Wigmore 1983; see Dugatkin 2003 for more information about the "information-center hypothesis").

Fishers may also acquire "real-time" information on patch quality based on other fellows' information. For example, in São Francisco, all boats have a radio system that permits information exchange (for detailed discussion about information in fisheries, see Mangel and Clark 1983; Durrenberger and Pálsson 1986). Consequently, what other fishers are doing may also influence the decisions of a particular trawler (Durrenberger and Pálsson 1986). Although various approaches have been used to understand the acquisition and distribution of information among fishers (e.g., Swain and Wade 2003; Holland and Sutinen 2000), evolutionary game theory (Maynard Smith and Price 1973) is a particularly suitable framework for understanding these aspects of behavior, but it is still poorly explored by studies on fisheries. Also, our study did not tested the OFT assumption that foragers have complete information of their environment, and this could be an important avenue for future research.

Economic variables are intimately related to the currency used to test OFT models. Several studies have found that monetary return may be a good currency for the OFT models, especially when fishers sell (at least) part of their catches (Begossi and Richerson 1992; Aswani 1998a, b; Nehrer and Begossi 2000; Lopes 2008b; Begossi *et al.* 2005). Our results are not conclusive in this regard. When total catches were considered, monetary return seems to fit the model better than biomass return, because correlation is higher for monetary return (Table 3). However, when only target species were considered on the linear regression analysis, the correlation is higher with biomass return (Table 3). Because of the market-oriented characteristic of the system studied (virtually all catches are sold to the cooperative as soon as they are landed), we would expect that money would be a better predictor for fishers behavior than biomass, but this trend was not observed.

Although at first glance the gross return rate for shrimp fishers from São Francisco seems to result in a high income (R$ 16.44 h^{-1} man^{-1}), the expenses of such activity are also very high. Lopes (2008b) evaluated the main expenses of trawling fishers in Guarujá (also in São Paulo Coast), a very similar fishing community in terms of boat length and trawling activity. After adding the costs of fuel, ice, food and maintenance, the annual average expenses per trip is R$ 61.51. Taking these variables into consideration, we suggest that the threshold estimated in this work (average gross financial return rate of all fishing grounds used) may be used as an indicator in future studies to evaluate different decisions across communities or across different time scales. According to Petrere *et al.* (2006), financial data are important to understand fishers' behavior and motivations and thus to assess how management policies affect them. Nevertheless, financial data are seldom collected in small-scale fisheries.

Insights from OFT on Shrimp Fisheries Management

Other research has suggested that understanding fishers' behavioral dynamics is an important step towards effective management (e.g., Hilborn 1985; Salas and Gaertner 2004). In that regard, can OFT contribute to effective fisheries management? What are the implications of confirming the predictions of the Optimal Foraging models for fisheries management?

The first contribution that OFT can offer to management is the organization and standardization of data collection. According to Aswani (1998a), the use of OFT methods can help anthropologists, geographers, and human ecologists to standardize field data. Such standardized data collection can increase the opportunities of researchers to compare different sets of data. Moreover, given the lack of systematic data about fish production in Brazil, our study presents valuable information about small-scale shrimp production.

Secondly, OFT provides a lens to analyze behaviors with regards to resource sustainability. Confirmation of the OFT hypothesis suggests that fishers optimize their short-term interests by harvesting resources as efficiently as possible. According to Alvard (2007), conservation occurs when individuals reduce their level of resource use below what would maximize fitness in the short-term. On the other hand, if individuals are maximizing their short-term returns, they are not compromising their present gains for future generations' benefits, which characterizes a non-sustainable practice. In addition, models derived from OFT can be used to uncover the underlying motivation of fishers to explore resources and fishing grounds (Begossi 2008).

Finally, the use of OFT can provide managers with information about fishers' preferences regarding the use of fishing grounds. This information can help managers in order to establish areas for resource refuge. Evidence suggest that if fishers are exploring resources as efficiently as possible (which was identified in our study), without a proper refuge area, resources tend to be overexploited (Joshi and Gadgil 1991). On the other hand, if fishers' most preferred areas are closed, such a management measure is less effective than if less preferred areas are used as refuges (Aswani 1998b). Using the CPF model to evaluate fishers' behavior we could identify fishing grounds that are less preferred by fishers, at least temporarily. However, the destructive effects of trawling activity (Jones 1992) must be taken into account when managing shrimp fisheries.

Conclusion

It is a widely accepted notion among fishers that choosing a good and profitable fishing ground may be based more on intuition than rational choice (i.e., "the skipper's effect" according to Durrenberger and Pálsson 1986), given the unpredictable and non-visible characteristics of the prey. Models derived from OFT, however, helped us identify two main variables that influence the fishers' decisions: a particular fishing ground's return rate on the last trip and the distance to the fishing ground. Fishers avoid fishing grounds with low return rates on the last trip and return more often to patches where they had higher returns. In addition, fishers stay longer and return with larger catches when they travel to more distant fishing grounds. Even though there are other variables that may influence fishers' decisions, such as environmental conditions and information exchange among individuals, we were able to make good predictions about fishers' behaviors when searching, capturing, returning home, and selling their catches.

As long as fishers explore resources as efficiently as possible in the absence of an appropriate refuge, resources tend to be exhausted (Joshi and Gadgil 1991). Such a trend will cause severe social and environmental damages. Top-down management measures (decisions centralized at the government level), which are still widespread in Brazil, have proven to be ineffective to improve both social and environmental aspects of fisheries. More interdisciplinary approaches are needed to deal with integrated social-ecological systems (Berkes *et al*. 2003). The approach used in this work can reveal less desirable fishing grounds that could be used as locally more acceptable refuge areas (Aswani 1998b), although management strategies must be carefully analyzed, especially when the fishing technology has many destructive effects (Jones 1992).

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