



UNIVERSIDADE ESTADUAL DE CAMPINAS

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**“Análise das Estratégias da Pesca do Camarão de São Francisco,
São Sebastião - SP, pela Teoria do Forrageio Ótimo”**

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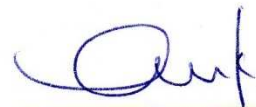
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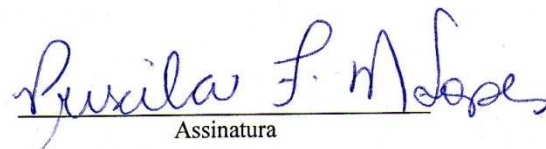
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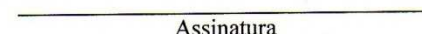
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RESUMO

Este estudo utiliza modelos ecológicos derivados da Teoria do Forrageio Ótimo (TFO) para compreender os processos de tomada de decisão entre os pescadores de arrasto de camarão do bairro São Francisco, no município de São Sebastião, SP. Tendo a Ecologia Comportamental Humana como ferramental teórico, o objetivo geral deste trabalho foi analisar as estratégias dos pescadores utilizando os modelos da TFO para elaborar hipóteses sobre a atividade pesqueira de pequena escala. Considerando os benefícios e custos do comportamento de forrageio (procura, captura, aquisição e consumo do alimento), os modelos derivados da TFO predizem as soluções mais econômicas para o forrageador. Neste trabalho procurou-se testar as seguintes hipóteses: 1) quanto mais longe for o ponto de pesca utilizado pelo pescador, maior deve ser o tempo que ele permanecerá pescando e, conseqüentemente, maior o retorno obtido; 2) o pescador escolherá o ponto de pesca de acordo com o retorno da última viagem. Os métodos de coleta de dados utilizados consistiram basicamente em questionários padronizados e observações diretas realizadas durante os desembarques pesqueiros (N=77). As atividades de desembarque de 28 pescadores foram registradas de forma sistemática ao longo de 22 dias consecutivos, entre 16 de abril e sete de maio de 2008, no principal ponto de desembarque do bairro São Francisco. Do total de 6.766 Kg de pescado desembarcados, camarões representaram 76,04%. As espécies mais capturadas foram o camarão sete-barbas (*Xiphopenaeus kroyeri*) e o camarão branco (*Litopenaeus schmitti*). Os pescadores utilizaram 19 pontos de pesca no período de estudo. Conforme previsto pela TFO, os pescadores permaneceram mais tempo em atividade de arrasto quando viajaram a pontos de pesca mais distantes, obtendo maiores retornos (financeiro e em biomassa). Além disso, a média da taxa de retorno financeiro

bruto dos pontos de pesca foi utilizada como parâmetro para avaliar a escolha dos pontos de pesca. Quando a taxa de retorno na última viagem foi menor do que a média, os pescadores mudaram de ponto de pesca mais freqüentemente ou, por outro lado, voltaram ao mesmo ponto de pesca quando a taxa de retorno na última viagem esteve acima da média ($\chi^2 = 4.7$; $p < 0.05$; $n = 49$; $df = 1$). As decisões dos pescadores em relação à escolha dos pontos de pesca são baseadas em experiências prévias, numa escala de tempo diária. Os pescadores estão explorando o recurso local da forma mais eficiente possível, maximizando o retorno financeiro em curto prazo, o que pode ser um indício de que os recursos podem ser exauridos em longo prazo. Desta forma, é urgente e necessária a elaboração de estratégias de manejo no local. Os métodos utilizados para testar hipóteses da TFO fornecem informações importantes sobre o uso dos pontos de pesca, por exemplo, que podem ser usadas para guiar a escolha de áreas de proteção do recurso (refúgios).

ABSTRACT

This study uses ecological models derived from the Optimal Foraging Theory (OFT) to understand the decision-making processes among bottom trawling shrimp fishermen at the São Francisco Neighborhood, in the district of São Sebastião, SP, Brazil. Using the theoretical background of Human Behavioral Ecology the aim of this work was to analyze fishermen's strategies using OFT models to raise hypotheses about the small-scale fisheries activity. Taking into consideration benefits and costs associated to the foraging behavior (search, capture, handling, and consumption), models derived from OFT predict the most economic behavior of the foraging animal. In this work we tested two main hypotheses: 1) the further the fishing ground, the longer the time fishermen will stay fishing, and consequently, the higher the return obtained; 2) fisherman will choose the fishing ground according to the last trip's return. Sampling methods consisted basically in closed-end questionnaires and direct observations made during fishing landings (N=77). Fishing landing activities of 28 fishermen were registered during 22 consecutive days (from April 16th until May 7th, 2008) at the main landing point of São Francisco neighborhood. Shrimp represented 76.04% of the 6,766 Kg total landed. Among them, the most captured species were sea bob shrimp (*Xiphopenaeus kroyeri*) and the white shrimp (*Litopenaeus schmitti*). Fishermen used 19 different fishing grounds during the period studied. As predicted by OFT, fishermen trawled longer when they traveled to further fishing grounds, obtaining higher returns (money and biomass). The average gross return rate of the fishing grounds was a good parameter to evaluate different decisions concerning fishing ground choices. When the return rate of the previous trip was below the average, fishermen changed the fishing ground more often, returning to the same fishing ground more

frequently when the return rate of the previous was above the average ($\chi^2= 4.7$; $p<0.05$; $n=49$; $df=1$). Fishermen's decisions concerning the choice of fishing grounds were based on previous trips experiences, on a daily base. In addition, fishermen are exploiting local resources as efficiently as they can, maximizing the short term financial return. This behavior can lead to resource depression in the long term, thus it is very important to build local management strategies. Methods used to test OFT hypotheses provide important information about fishing grounds use, for example, which can be used to guide the choice of no-take areas (refugees) when developing management strategies.

INTRODUÇÃO GERAL

Esta dissertação destina-se a entender os processos de tomada de decisão de pescadores de arrasto de camarão da comunidade de São Francisco, município de São Sebastião, SP. Serão utilizados modelos ecológicos derivados da Teoria do Forrageio Ótimo para avaliar as diferentes estratégias de pesca empregadas no sistema em questão. A finalidade deste trabalho é compreender como as variáveis sócio-ambientais influenciam a captura do recurso pesqueiro e moldam a interação de um grupo de seres humanos com a sua presa-alvo, o camarão sete-barbas (*Xiphopenaeus kroyeri* Heller). Este estudo está baseado nas idéias da Ecologia Comportamental Humana, campo caracterizado por empregar métodos desenvolvidos para o estudo do comportamento animal, para responder perguntas sobre os seres humanos (Laland e Brown, 2002).

Na primeira parte desta dissertação apresento uma revisão sobre a Teoria do Forrageio Ótimo e seus principais modelos. Em seguida, apresento os objetivos geral e específicos deste trabalho. No Capítulo I estão descritos os métodos utilizados e os principais resultados desta pesquisa. Por fim, é apresentada a conclusão geral da dissertação.

A Teoria do Forrageio Ótimo

A Teoria do Forrageio Ótimo (TFO) teve início na publicação de dois artigos na revista *American Naturalist* no ano de 1966, um dos pesquisadores R. H. MacArthur & E. R. Pianka e, no mesmo volume, o de J. M. Emlen. Estes trabalhos trouxeram para o estudo

do comportamento de forrageio¹ dos animais uma abordagem matemática econômica em face à similaridade, segundo eles, do desenvolvimento de teorias em economia e biologia populacional. Para esses autores, diferentes fenótipos apresentam diferentes habilidades para conseguir o alimento. Desta forma, o animal que conseguir o alimento da maneira mais “econômica”, considerando-se uma dada “moeda de troca” (geralmente energia), será favorecido pela seleção natural. Nos anos subseqüentes ao dessas publicações, muitos trabalhos foram publicados utilizando tais modelos matemáticos (e muitos outros modelos desenvolvidos) para compreender os processos de tomada de decisão durante o comportamento de forrageio animal (Stephens e Krebs, 1986). Um animal que conseguir maximizar a taxa de consumo de energia por unidade de tempo poderá alocar o tempo ou a energia poupada para suprir outras demandas conflitantes, tais como reprodução, defesa do território ou fuga de predadores, por exemplo.

A lógica por trás da maximização da taxa de consumo de energia é que através dela os forrageadores estariam maximizando o seu valor adaptativo (*fitness*), o que em última instância é favorecido pela seleção natural. Entretanto, devido à dificuldade de se medir o *fitness* como moeda de troca em grupos humanos, a taxa de consumo energético é utilizada como parâmetro de aproximação. Segundo Kaplan e Hill (1992), essa aproximação será verdadeira se pelo menos uma das seguintes condições forem observadas: 1) mais comida leve ao aumento da fertilidade ou sobrevivência; 2) maior tempo gasto em atividades que não sejam forrageio leve a um aumento na fertilidade ou sobrevivência; ou 3) durante o tempo gasto forrageando, o animal fica exposto a predadores perigosos, patógenos ou condições ambientais que reduzem a fertilidade ou sobrevivência. Maximizar a taxa de

¹ Entende-se por forrageio o processo de procura, captura, manipulação e consumo de uma determinada presa (ou determinado item alimentar).

consumo de energia parece ser bastante apropriado uma vez que o tempo destinado para cada atividade é limitado, há riscos associados ao comportamento de forrageio, ou ainda, os ganhos adicionais de energia podem ser usados para atividades que aumentem a probabilidade de deixar descendentes (Orians e Pearson, 1979). Animais que possuem uma demanda fixa de energia devem minimizar o tempo necessário para adquiri-la, sendo chamados de “minimizadores de tempo”. Os animais com uma quantidade limitada de tempo para forragear, devem maximizar a aquisição de energia por unidade de tempo, sendo chamados “maximizadores de energia” (Schoener, 1971).

Os primeiros trabalhos estudaram o comportamento de forrageio conforme quatro categorias (Pyke *et al.*, 1977): dieta ótima - que tipo de alimento comer; escolha da mancha - em que local comer; alocação de tempo na mancha - quanto tempo permanecer comendo em um local; e trajeto do forrageio - padrões otimizados e velocidade dos movimentos. Algum tempo depois, Orians e Pearson (1979) adicionaram mais um fator ao estudo do comportamento de animais, o retorno ao local central de alimentação para que não consumem a presa no local de captura, mas retornam com a presa. O modelo decorrente dessa modificação ficou conhecido como forrageio ótimo a partir de um local central (Pyke, 1984).

Além do pressuposto básico de que aumentar a eficiência do forrageio aumenta a aptidão do animal, os modelos da TFO compartilham três componentes: decisão, moeda de troca e restrições (Stephens e Krebs, 1986). A decisão é o tipo de problema que o modelo se propõe a entender. Por exemplo, o modelo de escolha de presa (ou dieta ótima) investiga que tipos de presas o animal deveria explorar. A moeda de troca é o parâmetro operacional utilizado para avaliar as diferentes decisões. Exemplos de moedas de troca são: energia, lipídios, proteína ou dinheiro. Restrições são todos os fatores que limitam e definem as

relações entre as variáveis decisão e moeda de troca. Os modelos convencionais de forrageio possuem três premissas de restrições: exclusividade de procura e exploração (ou procura, ou explora a presa), encontros aleatórios e seqüenciais (distribuição de Poisson) de presas ou manchas no ambiente, e informação completa sobre o ambiente. Apesar de parecerem bastante irrealistas as premissas dos modelos convencionais, devemos nos lembrar que modelos são simplificações da complexidade da realidade permitindo que entendamos alguns padrões gerais, desde que tais modelos sejam também robustos. O próximo tópico apresenta uma revisão dos principais modelos da TFO.

Os modelos da Teoria do Forrageio Ótimo

Dieta ótima (ou escolha de presas)

Os modelos que predizem a dieta ótima de um forrageador assumem que os itens alimentares são escolhidos durante o forrageio de forma a maximizar a taxa de consumo de energia ou massa (medidas em calorias e unidades de peso, respectivamente) levando em conta o tempo de procura e manuseio da presa. Desta forma, os itens alimentares poderiam ser ordenados de acordo com a razão entre o retorno energético e o tempo gasto na procura e no manuseio (captura e consumo) da presa.

Deste modelo decorrem três propriedades. A primeira é que a seleção de uma presa para consumo não depende da sua própria abundância no ambiente e sim da abundância absoluta dos itens “preferidos”. A segunda é que conforme a abundância do item preferido aumenta, a probabilidade dos itens “menos preferidos” serem selecionados diminui. A última propriedade é que um determinado item é incluído ou retirado da dieta de forma absoluta (Pyke *et al.*, 1977). É interessante notar que a primeira propriedade é bastante contra-intuitiva e, mesmo assim, vem sendo comprovada em vários estudos de

comportamento animal, incluindo grupos humanos (Pyke, 1984; Hames e Vickers, 1982; Hawkes *et al.*, 1982; Setz, 1983; O'Connell e Hawkes, 1984; Thomas, 2007; Kaplan e Hill, 1992). Entretanto, algumas modificações no modelo foram propostas para torná-lo mais robusto, tais como considerar a inclusão parcial de um item na dieta ou a escolha de uma moeda de troca mais fiel à realidade observada.

Pyke (1984) ressalta alguns pontos que merecem bastante atenção ao se interpretar as previsões do modelo de dieta ótima. Podem-se encontrar situações onde a inclusão ou exclusão de um item da dieta seja parcial. Desta maneira, devem-se incluir além das médias, as variâncias dos valores energéticos dos itens alimentares. Preferências por itens alimentares que dependam mais da sua abundância do que da abundância de itens preferidos podem ser selecionadas nas seguintes situações: se a aptidão do predador depender de mais de um valor alimentar, como quando há escassez de um nutriente. Neste caso, os itens selecionados são aqueles que apresentem este nutriente, independente de serem preferidos; se o reconhecimento da presa leva tempo e é impreciso; quando a presa é críptica; e quando o tempo de manuseio da presa dependa da experiência do animal a manuseá-la.

Estudos antropológicos que utilizaram o modelo de escolha de presas de forma geral corroboraram as previsões do modelo (Hames and Vickers, 1982; Hawkes *et al.*, 1982; Setz, 1983; O'Connell and Hawkes, 1984; Thomas, 2007; ver Kaplan and Hill, 1992 para uma revisão detalhada. A moeda de troca mais utilizada foi energia (medida em calorias). Entretanto, alguns estudos chamam atenção ao fato de que a inclusão de outras variáveis para este propósito pode tornar os modelos mais realistas. Begossi e Richerson (1992), por exemplo, utilizaram a quantidade de espinhas (uma medida de dificuldade de manipulação) e dinheiro obtido na venda do pescado para prever a inclusão de itens na dieta. Estes

pesquisadores argumentam que incluir outras variáveis além de calorias pode tornar os modelos da TFO mais robustos quando aplicados a populações humanas.

Escolha e alocação de tempo nas manchas

Quando as presas ocorrem de forma agregada no ambiente, tais agregações são chamadas de manchas de recurso. O modelo de escolha de manchas pode ser interpretado da mesma forma que o modelo de dieta ótima. Por este modelo, os forrageadores tenderão a se alimentar nas manchas de alimento onde o retorno energético é maior, otimizando, assim, o uso das manchas de recursos (MacArthur e Pianka, 1966). Entretanto, a maioria dos estudos sobre manchas de recurso até hoje focaram a decisão de quanto tempo o animal deve permanecer forrageando dentro da mancha (Kaplan e Hill, 1992), e não na escolha de manchas em si. O tempo que um forrageador deve permanecer em uma mancha até abandoná-la e partir para uma outra mancha de recurso é avaliado pelo teorema do valor marginal proposto por Charnov (1976). A idéia envolvida é que, conforme um animal permanece forrageando em uma mancha, o recurso tende a diminuir até um momento onde não será mais vantajoso para o animal permanecer na mancha. O modelo determina que um forrageador deve permanecer em uma mancha até que o retorno energético imediato torne-se menor ou igual ao retorno médio das outras manchas do ambiente. Desta forma, deve-se assumir que o animal sabe a qualidade de todas as manchas do ambiente e o tempo necessário para chegar até elas.

Outra premissa básica dos modelos que predizem o comportamento de animais em manchas de recurso é que o retorno dentro da mancha é uma função do tempo de permanência dentro dela. Esta função é negativamente acelerada, tendo em vista que na

maioria das vezes a quantidade de recursos dentro da mancha é limitada (Stephens e Krebs, 1986).

Alguns problemas foram encontrados na utilização dos modelos de escolha e alocação de tempo nas manchas. Smith e Dawkins (1971) aplicaram o modelo de escolha de manchas para compreender o comportamento de uma espécie de pássaro (*titmice*) cujos indivíduos forrageavam entre manchas de diferentes qualidades de recursos. Contrariando o esperado pelo modelo, os animais não permaneceram forrageando exclusivamente nas manchas preferidas, mas permaneceram mais tempo nas manchas de maior qualidade e progressivamente menos tempo nas manchas de qualidade progressivamente menor.

Em grupos humanos, alguns estudos mostraram que apesar de utilizarem as manchas de maior rendimento mais frequentemente, os forrageadores não as exploram exclusivamente (Smith, 1991; O'Connell and Hawkes, 1984; Beckerman, 1983; Sosis, 2002). Estudando pescadores de camarão na Baía de Sepetiba, Begossi (1992) utilizou o Teorema do Valor Marginal para estimar o tempo de permanência dos pescadores no ponto de pesca. De forma geral, os pescadores permaneceram mais tempo dentro da mancha do que a previsão do modelo. Uma freqüente explicação *ad hoc* para tais observações é que deve haver variações diárias na qualidade das manchas, de forma que a mancha mais produtiva em um dia pode não ser a mancha mais produtiva todos os dias. Entretanto poucos estudos até hoje testaram esta hipótese (Sosis, 2002).

Otimização de movimentos e velocidade

Os trabalhos que tratam da otimização de movimentos geralmente testam a hipótese de que o forrageador deve movimentar-se mais linearmente até encontrar uma presa e, quando a presa é encontrada, o predador tende a mudar de direção mais constantemente, de

forma que esta seria uma adaptação para o consumo presas que ocorrem de maneira agregada (Pyke *et al.*, 1977). Cody (1971) defende que a otimização do movimento de um animal depende da capacidade que o animal tem em não transitar por um caminho já percorrido. Desta maneira, o animal estaria maximizando a taxa de encontro com os itens alimentares. A otimização da velocidade de movimentação dos forrageadores é muito pouco estudada sob a ótica da teoria do forrageio ótimo (Pyke, 1984).

Forrageio ótimo a partir de um local central

Forrageadores que exploram manchas e retornam para um local fixo onde as presas são consumidas ou processadas são analisados pela teoria de forrageio a partir de um local central (Orians e Pearson, 1979). Este modelo permite analisar problemas de duas categorias. A primeira é constituída pelas decisões que o forrageador deve tomar quanto à seleção de manchas, presas e tamanho da carga. A outra categoria procura responder questões sobre o tamanho ótimo de um grupo de caça e onde eles deveriam estabelecer um local central numa excursão de caça muito longa. Este modelo mescla características de dois modelos distintos de forrageio ótimo: o modelo de dieta ótima, visto que os predadores devem escolher a presa na mancha; e o modelo de escolha de manchas, já que uma decisão a ser tomada é qual mancha explorar (Pyke *et al.*, 1977).

Grupos humanos freqüentemente retornam para suas casas após forragearem (Kaplan e Hill, 1992). Esta característica é especialmente verdadeira para a atividade pesqueira, o que faz do modelo de forrageio a partir do local central muito apropriado para avaliar o comportamento e as estratégias dos pescadores (Begossi, 1992; Bird e Bliege Bird, 1997; Seixas e Begossi, 2000; Begossi *et al.* 2005; Begossi, 2008; Lopes, 2008b; Begossi *et al.*, 2009). Segundo Orians e Pearson (1979), o modelo de forrageio a partir do

local central possui três unidades básicas: uma viagem até a mancha, um período de forrageio na mancha e uma viagem de retorno. O gasto energético ocorre nas três fases, mas a aquisição somente na segunda. Desta forma, os forrageadores devem compensar os gastos inerentes da viagem permanecendo mais tempo nas manchas mais distantes visando entregar uma maior quantidade de recursos no local central. As previsões do modelo são: o tempo de permanência na mancha e o tamanho da carga aumentam conforme aumenta o tempo de viagem. Neste trabalho, estas previsões serão usadas para elaborar hipóteses testáveis sobre as estratégias de pesca dos pescadores de camarão da comunidade São Francisco - São Sebastião, SP.

Nesta dissertação serão abordados tanto o modelo de escolha de manchas, quanto o modelo de forrageio a partir do local central para avaliar as diferentes estratégias de pesca de arrasto de camarão. Diferentemente de outros trabalhos publicados sobre este assunto, este trabalho levou em conta as variações que ocorrem em escala diária de tempo, analisando decisões em dias consecutivos. No Capítulo intitulado *Optimal foraging among Brazilian shrimp fishermen: travel time and daily variations in patch quality influence decisions*, estão relatados, de forma mais completa, a área de estudo, os métodos empregados, os resultados obtidos e uma discussão sobre os aspectos mais relevantes do trabalho considerando a literatura já feita sobre o assunto.

OBJETIVOS

Objetivo geral

O objetivo geral deste trabalho é analisar as estratégias de pesca de um grupo de pescadores de arrasto de camarão do bairro São Francisco (São Sebastião, SP), utilizando os modelos ecológicos da Teoria do Forrageio Ótimo como o arcabouço teórico para formular hipóteses testáveis sobre as decisões tomadas pelos pescadores em uma escala diária. A hipótese básica é que a decisão diária de onde o pescador vai pescar em um determinado dia pode estar relacionada com o retorno obtido nas viagens anteriores nas diferentes manchas de recurso do ambiente.

Objetivos específicos

Com o intuito de compreender os processos de tomada de decisão dos pescadores de arrasto de camarão, buscou-se testar as seguintes hipóteses:

- Os pescadores devem retornar com mais frequência aos pontos de pesca cujo rendimento na última viagem tenha sido superior ao rendimento médio de todos os pontos de pesca utilizados. Caso contrário, a decisão mais comum deverá ser trocar o ponto de pesca;
- Os pescadores permanecerão mais tempo arrastando quando viajarem a pontos de pesca mais distantes e, conseqüentemente, obterão maiores retornos (financeiro e em biomassa);
- Frente ao caráter comercial do sistema analisado, o retorno financeiro será capaz de prever as diferentes decisões dos pescadores, se empregado como moeda de troca nos modelos de forrageio ótimo.

CAPÍTULO I

Optimal foraging among Brazilian shrimp fishermen: Daily variations in patch quality influence decisions

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Key words: Optimal Foraging Theory, shrimp fisheries, Patch Choice, Central Place Foraging, decision-making process

Abstract

Studies using Optimal Foraging Theory to understand human behavior have stated that daily variation in patch profitability could explain mismatches with predictions of patch choice models. In this paper, we tested whether the return rate of a particular fishing trip could predict fishermen's choices to return or choose a different fishing ground for their next trip. We collected data on 77 fishing trips during 22 consecutive days by interviewing fishermen at the main landing point of a small-scale shrimp fishing community on Brazil's southern coast. As predicted, fishermen returned more often to fishing grounds where the return rate of the previous fishing trip was above the average gross return of the environment (R\$16 man⁻¹ hour⁻¹), but otherwise they went to a different fishing ground ($\chi^2 = 4.7$; $p < 0.05$; $n = 49$; $df = 1$). Daily variations in patch quality accounted for fishermen's decisions, but other variables may also influence the observed behavior, such as scale of analysis, within-day variations, and the method used to evaluate decisions.

Introduction

The Optimal Foraging Theory (OFT) can be defined as a *corpus* of formal theoretical models sharing the basic assumption that maximizing the rate of nutrient acquisition enhances an individual's fitness, either by increasing nutrient intake or by reaching some intake threshold more quickly, thereby freeing time to pursue other fitness-related activities (Bird and O'Connell, 2006). This assumption is based on the principle that individuals face trade-offs between managing energy and time: if an animal can acquire food in a more economical way, given some currency, this animal can be favored by Darwinian natural selection (Kaplan and Hill, 1992). This body of theory had its beginning with back-to-back publications in the *American Naturalist* magazine in 1966, the first by MacArthur and Pianka and the second by Emlen. During the following years, many researchers used these mathematical models to formulate testable hypotheses about the decision-making processes concerning animals' foraging behavior (Stephens & Krebs, 1986).

Besides the same basic assumption, foraging models share three components: decisions, currencies and constraints (Stephens and Krebs, 1986). The decision component is the kind of problem the model is designed to solve, for example, which prey type a forager should exploit. Currency is the measurement scale used to evaluate different decisions. Some examples of currencies are energy, protein, lipids, and money. Constraints refer to all of those factors that limit and define the relationship between the currency and the decision variable(s). Conventional foraging models make three constraint assumptions: exclusivity of search and exploitation, sequential Poisson encounters of prey or patches (clumps of resources), and complete information of the environment. Failures to confirm

the model's predictions have often led to searches for more appropriate constraints or currencies (Kaplan and Hill, 1992; Stephens and Krebs, 1986) or to the development of new models.

Patch Choice and Central Place Foraging Models

When prey is non-randomly distributed in the environment or aggregated in clumps or patches, predicting which patch will be exploited is possible through the Patch Choice Model (MacArthur and Pianka, 1966; Charnov and Orians, 1973). In this model, there are two main decision components: 1) Should a forager enter a patch or continue searching other patches? 2) After deciding to enter a patch, how long should the forager stay there? As for the prey choice model, the currency most frequently used to evaluate alternative decisions is energy. The constraints for the Patch Choice Model are similar to those of Prey Choice, but a different and important additional constraint is that resource patches have generally decreasing gain functions, given that virtually all patches have a finite quantity of resources (Stephens and Krebs, 1986). If foragers are able to perceive resource clumping, they are expected to use it to maximize their average foraging return rates (Kaplan and Hill, 1992). To date, most of the studies using the patch choice model have addressed the second decision since most models are primarily designed to predict how long a forager should remain in a patch (Kaplan and Hill, 1992). Begossi (1992) used the Marginal Value Theorem (Charnov, 1976), a model of patch choice, to predict how long shrimp fishers should stay in a patch. In general, shrimp fishers remained in the patch longer than was expected by the model. Other studies found that, although human foragers exploited the most profitable patches more frequently, they did not exploit them exclusively (Smith, 1991; O'Connell and Hawkes, 1984; Beckerman, 1983). A frequently cited *ad hoc*

explanation for these observed results is based on daily fluctuations in patch quality (Kaplan and Hill, 1992; Sosis, 2002). Sosis (2002) stated that if daily fluctuations in environmental conditions do not equally impact the profitability of patches across a habitat, the most profitable patch on average may not be the most profitable patch every day. Nevertheless, few studies have addressed this question to date.

Another foraging problem addressed by the OFT is when foragers return to a central place to consume the food captured. Humans generally return to a central place after they forage (Kaplan and Hill, 1992). This is especially true for fishers, which makes Central Place Foraging (CPF) models very applicable to fishing (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. One decision component of CPF explored in studies of fisheries concerns the optimal load size to be transported home (central place) given the distance traveled to the foraging site. Assuming that the costs of travel increase with distance to the patch, the predictions of the model are: 1) optimal load size increases with the distance to the central place, and similarly, 2) time searching inside the patch increases with distance to the central place. Both of these predictions could be used to develop hypotheses about fishermen's behavior when searching for, capturing and carrying back shrimp. Thus, this study aims to explore OFT as a tool to understand shrimp fishermen's behavior through a case study in a small-scale fisheries community, São Francisco, located on the southern coast of Brazil.

Using OFT to build testable hypotheses about the behavior of shrimp fishermen

There are two kinds of decisions that can be abstracted from shrimp fishing activity: a decision that precedes the trip, that is, where the fisherman should go fishing on that day, and a decision coming after the trip, namely how long a fisherman should stay in his chosen patch once he has traveled to it.

Evidence exists to indicate that the first kind of decision may be influenced by the success of previous captures. Sosis (2002), studying the Ifaluk fishers from Micronesia, found that fishermen exploited alternative patches (but did not exploit the most profitable ones) when the return rate of the previous day (or previous morning) was below the overall per capita return rate of alternative patches. Eales and Wilen (1986) studied the pink shrimp fisheries and demonstrated that fishermen are influenced by relative abundance information from the previous day. Based on these data, in addition to the argument that exploitation of resource patches may be influenced by daily variations of patch quality (Kaplan and Hill, 1992), we raise the first hypothesis of this work: Fishermen will prefer to return to the same fishing ground they visited the previous day if their gross return rate ($R\$/\text{hour} \cdot \text{man}$) on that day was above the average gross return rate of the environment; otherwise, they would rather change fishing grounds.

The second kind of decision fishermen face, after they have decided on and traveled to the fishing ground, could be evaluated through a CPF model (Orians and Pearson, 1979). Assuming that fishing grounds are patches of resources and have negatively accelerated gain curves, we raise three other predictions: 1) the longer the fishing trip (travel time to and from the fishing spot), the more time fishermen will spend trawling; 2) the longer the fishing trip, the greater the amount of catch landed (in Kg) and the greater the gross financial return; and 3) the longer the time spent trawling inside a fishing ground, the

higher the returns (in biomass and money). The Marginal Value Theorem (MVT) predicts that animals should exploit a patch of resource as long as the instant return rate of the patch is greater than the average return rate of the environment. So, foragers should leave a patch when the costs of searching for more prey overtake the costs of traveling to a more profitable patch. Although the third prediction is not a real test of the MVT, Smith (1991) argued that it is a valid correlate under specific assumptions: patches experience negatively accelerated gain curves, gain curves do not overlap one another, and each patch can be exploited in a given day. Gain curves have never been properly measured in studies with humans since doing so implies experimentally manipulating the quality of patches (Sosis, 2002). This assumption is not tested in our study, though it is reasonable to assume that prey becomes scarce inside a patch as a function of time because of harvesting, movement of prey, and changes in tide and wind conditions, for example.

Study area

The northern coast of São Paulo State is 161 km long and is composed of 164 beaches and 17 islands. It encompasses the districts of Ubatuba, Caraguatatuba, São Sebastião and Ilhabela (Souza and Begossi, 2007). The district of São Sebastião (23°42'18" to 23°45'38"S – 45°25'41" to 45°53'49"W) is composed of a narrow plain 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 tropical wet (Af), following Köppen's classification. The average annual temperature is 24.8°C (Cepagri, 2009). The study was carried out in the São Francisco neighborhood, a small-scale fisheries community.

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 were relatively small, the average being 9.97 m in length (SD = 3.00; N = 20; Table 1). Boats were adapted for the pair trawl method, in which two lateral structures, called *tangones*, support one trawling net on each side of the boat. Each trawl net was 12.96 m wide on average (min = 5 m; max = 22; SD = 4.19; Table 1), and they work by dragging on the sand bottom of the sea. It is important to notice that in some boats, fishermen use one additional trawl net called a “try-net”. This is a kind of miniature trawl net and is used as a way of sampling the fishing spot at the beginning of the trawling activity. Implications of the use of the “try-net” are exposed later on the discussion of this manuscript.

Methods

Fishing landings were sampled during 22 consecutive days (from April 16 to May 7, 2008) at the Cooperpescass² in the São Francisco neighborhood. Interviews were conducted using closed questionnaires (Annex I – adapted from Begossi, 2004) at the moment of the catch landings’ weighing. We selected fishermen who were over 20 years old, had more than 10 years of experience fishing in the area, and were willing to participate in the study, which totaled 28 fishermen. The first time a fisherman was approached, the objectives of the study were explained, and only fishermen who agreed to participate in the study had their landings registered. Specific data about the boat and fishermen were also obtained in

² Cooperpescass – Fisheries Cooperative São Sebastião (23°45′22" S – 45°24′40"W) - a fish and shrimp processing plant where fishermen sell their catches and buy diesel and ice to store their captures. In this work, Cooperpescass is the fishing landing point (central place).

this first session, such as boat length and type, number and size of trawl-nets, fisherman's age, fishing time, and if he fished part- or full-time.

During the fishing landings, fishermen 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, net length, and number of crew. Arrival time was registered as the time when fishermen anchored their boats. Catches were separated according to selling categories (see Table 2), 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 identifications of the selling categories were based on Graça Lopes *et al.* (2002), Lopes (2008a) and Palomares and Pauly (2009). Fishing grounds were mapped jointly with an expert fisherman using a satellite image of the region at the end of data collection to assure that all spots mentioned by fishermen were located.

Based on other studies that successfully used financial return as currency (Aswani, 1998; Nehrer & Begossi, 2000, Lopes, 2008b), and also on the market-oriented character of the shrimp fisheries studied here (virtually all catches are sold to the fishing cooperative), we used both total biomass (Kg) and monetary return (in R\$) as currencies to evaluate fishermen's decisions.

The statistical analysis used in the study consists of two simple tests: chi-squared tests and simple linear regressions. To test the hypothesis that the decision of where a fisherman should go fishing is based on the rate of capture of the previous day, we performed a chi-squared test. For this analysis, we used data from 49 fishing trips for which we had accurate information on the previous day's fishing ground and gross return rate (R\$/hour/man).

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\$). In cases when fishermen visited more than one fishing ground in a single day, we considered the travel time to the first fishing ground when fishing grounds were contiguous to each other (adjacent beaches). We excluded from our regression analysis nine fishing trips when the different fishing grounds were far from each other, since we did not register the travel time between them. All data used in linear regressions were normalized using natural logarithm transformations. To test whether travel time explained gross returns, we used travel time to and from the fishing spot as the independent variable and gross financial return and catches (Kg) as dependent variables (N = 68 fishing trips). In addition, travel time to and from the fishing spot was used as an independent variable and trawling time as a dependent variable to test if travel time could explain the amount of time fishermen spent trawling (N = 68 fishing trips – in four trips we were unable to register the trawling time). Finally, trawling time was used as an independent variable and gross return (Kg and financial) as a dependent variable to test if trawling time is positively related to return (N = 73 fishing trips).

Results

Characterization of the trawling activity in São Francisco, São Sebastião – SP

Fishing activities of 28 fishermen were registered during the study. The shrimp fishing trips depart at 4:20 AM on average and return at 2:30 PM, even though some trips take more than 24 hours. Each trip is performed by one or two fishermen, generally the boat owner alone or the boat owner with one helper. The average age of the interviewed fishermen 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 (Table 1). Only one was a part-time fisherman; all others reported being full-time fishermen.

A total of 6,766.76 Kg of fish and seafood were landed at the São Francisco landing point (Table 2). Shrimp represented 76.04% (5.1 tons) of the total landed, while 23.8% (1.6 tons) were fish and only 0.15% 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 represented by a mix of several species (bycatch), generally including some demersal fish, such as *Menticirrhus americanus*, *Cynoscion jamaicensis* and *Paralichthys brasiliensis*, or some small individuals of *Trichiurus lepturus* and *Micropogonias furnieri*. Bycatch accounted for 18.22% of total catches and is commonly donated to poor people who help the fishermen with landings. Generally, when fishermen land small quantities of bycatch, it is all donated; however, when the quantities landed are higher (>20 Kg), it is sold to Cooperpescass at a very low price (from R\$ 0.50 to R\$ 1).

Figure 2 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 trip data are shown in Table 3.

Optimal Foraging Models predicting fishermen's behavior

From the Marginal Value Theorem (Charnov and Orians, 1973), we can expect that a forager should stay in a patch as long as the return rate of that patch is higher than the average return of the alternative patches. Although we did not actually test the MVT in this work, we adapted its prediction to account for daily decisions based on the previous trip return rate. Figure 2 shows that for 49 fishing trips, when the mean gross return rate (R\$ hour⁻¹ man⁻¹) of a fishing spot on the previous trip was below the mean gross return rate of the environment, the threshold value (R\$16.44 hour⁻¹ man⁻¹), trawlers changed fishing spots for the following trip more frequently than they returned to the same fishing spot. On the other hand, when the gross return rate of the fishing spot on the previous day was above the threshold, trawlers returned to that fishing spot more often than they changed to another ($\chi^2= 4.7$; $p<0.05$; $n=49$; $df=1$). These results indicate that daily decisions of where the trawlers go fishing may be predicted by the previous catch.

Following the hypothesis derived from the Central Place Foraging Model, we can expect that fishermen will compensate for longer travel times by: a) spending more time fishing and b) increasing their catches, consequently earning more money. The results shown in Table 4 confirm these predictions. Time spent trawling is positively related to travel time. Other variables being equal, 33.69% of the variation in time spent trawling can be explained by the travel time. Consequently, the longer fishermen take to reach the fishing ground, the larger the catches they bring to the central place (fish landing) and the

more money they earn, since 33.17% and 38.56% of the variation in biomass return and gross monetary return, respectively, can be explained by travel time. It is also true that the longer the fishermen spend trawling, the larger the catches they return with and the more money they earn, since trawling time explains 48.88% of the variation in the weight of the catches and 65.82% of the gross financial return. Although both biomass and monetary return were good currencies by which to evaluate fishermen's decisions, financial return fits the model better.

Discussion

By testing hypotheses about fishermen's behavior based on OFT, we were able to make two strong predictions: first, fishermen respond individually to daily variations in patch quality, avoiding low returns; and second, the further fishermen travel to fish, the greater the effort applied and, consequently, the higher the returns. Basically, these two strategies help fishermen maximize their profits by enhancing their efficiency, although maximization is not the unique goal of optimal foraging (Stephens and Krebs, 1986). As stated by Shoener (1971) a foraging animal concerned in running away from predators could be a time-minimizer. A comparison with other studies that used OFT to comprehend fishermen's behavior is helpful to understand which factors constrain optimal behavior and decision-making. Below we show the comparisons we made.

Scale of analysis may influence results related to foraging behavior. Our work shows that fishermen respond to daily fluctuations in patch quality, avoiding fishing spots with low returns during the previous trip. Sosis (2002) also found daily responses to patch quality in the fisheries in Micronesia. When the quality of the most profitable patches had

decreased below the average return of alternative patches, fishermen changed patches. Lopes (2008b) studied the fisheries in Guarujá (southern coast of São Paulo). 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. Seixas and Begossi (2000) found that individual analysis of fishermen's behavior using CPF models explained the observed behavior better than populational analysis. Eales and Wilen (1986) verified that when macro and micro geographic regions were compared, the former confirmed predictions about patch quality influencing daily decisions more accurately. This result shows that the geographic scale of analysis is an important variable to consider when trying to understand fishermen's decisions.

Although we found that fishermen returned to the same fishing ground according to the last trip's return rate, they did not change fishing grounds 100% of the time when the average return of the last trip was below R\$ 16.44 hour⁻¹ man⁻¹, for example. What are the other factors that may influence that decision based on that threshold? Dreyfus-Leon and Gaertner (2006) made a brief list of some of the factors that may influence fishermen's behavior, including fishermen's perception about the richness of the actual fishing area, previous success in the fishing area, cumulative searching time in the same area, information about the richness of the other fishing grounds, length of the fishing trip, observation of other vessels in fishing activity in the same area, and memory of the closest previous decisions. In addition, we could cite other environmental variables, such as climate and tide conditions, which could have an influence on prey distribution or on the decision not to travel to a further fishing ground if a storm is imminent, for example. Prey characteristics, such as mobility, were also indicated by Begossi (1992) and Begossi *et al.*

(2005). 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 about returning to or changing the fishing ground. Begossi *et al.* (2009) also stressed that the unpredictability of fish resources, along with their non-visibility, makes the extractive systems of artisanal fishing an activity based on "rules-of-thumb", probably based on previous experiences.

Although at first glance the gross return rate for shrimp fishers from São Francisco seems to result in a high income (R\$ 16.44 hour⁻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. Summing 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 Jr. *et al.* (2006), financial data are important to understand fishermen's behavior and motivations and thus to assess how management policies affect them. Nevertheless, they are seldom collected and mainly in small scale fisheries.

Daily fluctuations in patch quality are assumed to exist, but information about patch quality may vary even within a single day (Eales and Wilen, 1983). In the studied community, all boats have a radio system that permits information exchange (for detailed discussion about information in fisheries, see Mangel and Clark, 1983). In addition, what other fishermen are doing may also influence the decisions of a particular trawler, but these aspects of behavior are better understood by evolutionary game theory (Maynard Smith and Price, 1973).

In this work we assessed decisions based only on individual information (fishermen 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 fishermen's past experiences. In a given day, a fisherman coming from Guaecá (a fishing ground) landed a very high catch of white shrimp (about 252 Kg). On the following day, seven boats went to that same fishing ground (Guaecá), while only three fishermen decided to go to another. The landing point, in this case, may be functioning as an "information-center" where observers acquire information about patch quality from demonstrators, as observed in mammalian aggregations (Galef and Wigmore, 1983; see Dugatkin, 2003 for more information about the "information-center hypothesis").

Both the biomass of the catches and the financial returns are higher when fishermen go to more distant fishing spots, though the financial return fits better with our predictions. Fishermen maximize their short-term financial return more than simply their biomass return (however, these variables are related). The longer the time fishermen spend trawling, the higher the returns in biomass but mainly the higher the financial return. Differences in the precision of predicting the decisions according to the currency have also been found in other studies. Begossi (2002) found similar results in Sepetiba, since residence time (equivalent to trawling time in this work) explained both the number ($Y = 0.61 - 24.05 X$; $r^2=0.52$; $p > 0.001$) and the biomass ($Y = 0.02 - 0.2X$; $r^2=0.38$; $p > 0.001$) of the shrimp caught, although the number fits the model better. Nehrer and Begossi (2000) confirmed the predictions of the model only with high priced species and not with total biomass. In this work, monetary returns appear to be an accurate currency given the market-oriented characteristic of the studied system, since all catches are sold to the Cooperative as soon as they are landed. Many other studies have shown that money can be a good currency for

optimal foraging models applied to fisheries (Begossi and Richerson, 1982; Aswani, 1998; Nehrer and Begossi, 2000; Lopes, 2008b; Begossi *et al.* 2005).

The perception about the actual richness of the patch is another variable that may influence foraging behavior (Dreyfus-Leon and Gaertner, 2006). Fishermen 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 fishermen can collect it. The catches in the try-net reflect what is being caught in the main trawl net. If the catches in the try-net are good, the fisherman remain on that fishing ground; otherwise, he should look for another. If he does not use the try-net, he has to wait for approximately 1 h 40 min (average time of one trawl, Table 3) to sample the fishing ground. This strategy helps the fisher to acquire information on the fishing ground faster, thereby enhancing his efficiency.

Insights from OFT on shrimp fisheries management

Hilborn (1985) suggested that the collapses of many fisheries can best be explained as the result of misunderstanding fishermen's behavior, rather than a lack of knowledge of fishery resources. Salas and Gaertner (2004) stated that knowing the fishermen's behavioral dynamics is essential for effective management. Thus, the questions that remain are how can OFT contribute to the management of resources and what are the implications, to resource management, of confirming the predictions of the models? In this last topic of discussion, we will expose some answers to these questions found in the literature and provide an interesting insight about the management of shrimp fisheries based on formal theoretical models.

Confirmation of the foraging hypothesis suggests that fishermen optimize their short-term self interests by harvesting resources as efficiently as possible. This could lead to depletion or non-intentional conservation of the resource, depending on changing environmental conditions (Aswani, 1998a; Aswani, 1998b). As found in Alvard (2007), conservation occurs when individuals reduce their level of resource use below what would be fitness maximizing in the short term for long-term, sustainable benefits in the future. So, if individuals are maximizing their short-term returns, they are not intentionally reducing their present harvest effort for future generations' gains. OFT can be used to evaluate behaviors that at first glance can be seen as conservation practices, such as food taboos, but happen under a short-term maximization logic, characterizing a non-conservation practice.

Another managerial implication of the use of models derived from OFT is that we can understand what really motivates the fishermen (the currency). According to Begossi (2008), OFT can bring together two systems of thinking: the local (how fishers manage to obtain what they want) and the scientific (the variables that are part of the fisher's decision). Aswani (1998a) called attention to a methodological implication of the use of OFT models. The organized methodology and theoretical framework can help anthropologists and human ecologists organize and systematize their field data. In the face of the lack of data about fish (and shrimp) production in Brazil, OFT methodology could help gather such data.

Joshi and Gadgil (1991) developed a model to determine if resource users of a premarket economy could reach a MSY (Maximum Sustainable Yield) by increasing their effort of exploitation using simple rules of trial and error based on information of previous captures. The rules were as follows: if an increase in effort led to an increase in harvest, then the effort should be increased further; if an increase in effort has led to a decrease in

harvest, then the effort should decrease; if a decrease in effort has led to an increase in harvest, then the effort should decrease further; and if a decrease in harvest has led to a decrease in harvest, then the effort should increase. These rules are quite similar to those observed in our work related to fishermen's decisions on fishing grounds based on their last trip's information. What Joshi and Gadgil (1991) noticed after a simulation of this model is that in an open-access situation, the resource is exploited in a run-away increase process until the capital resource becomes exhausted. These researchers next evaluated how this model would work in the presence of a refuge, an area where no harvest is allowed (in fisheries management, we could call it a no-take area). They found that since the refuge was sufficiently large and the protected population could mix freely with the harvest population, no matter how high the harvest effort was, the resource population persisted (Joshi and Gadgil, 1991 – Figure 5, p.221).

The statement made by Joshi and Gadgil may be very simplistic since it does not consider the biological specificities of different species; however, this result provides an interesting insight about the management of shrimp fisheries since access restrictions to habitats temporarily considered less desirable would likely be more acceptable to local fishers than closing preferred areas (Aswani 1998b). It is also true that refuges alone are not a safe management measure given the bottom trawling technology used in this kind of shrimp fishing. Adverse side effects, such as low selectivity, habitat degradation and conflicts with other fishing technologies (for conflicts see Lopes, 2008b), may be taken into account also. According to Jones (1992), the management of fisheries that use technologies with low selectivity must take into account the side effects of the bottom trawling activity.

Conclusion

It is a widespread, commonsense notion that choosing a good and profitable fishing ground may be nothing but a moment of good luck, given the unpredictable and non-visible characteristics of the prey. Models derived from OFT, however, helped us to identify two main variables that influence the fishermen's decisions: a particular fishing ground's return rate on the last trip and the distance to the fishing ground. Fishermen avoid fishing grounds with low financial return rates on the last trip and return more often to the ones where they had higher returns. This kind of decision, preceding the trip, is dynamic and detectable through a daily scale of analysis. In addition, fishermen stay longer and return with larger catches when they travel to more distant fishing spots. Even though there are other variables that may influence fishermen's decisions, such as information exchange with other individuals, we were able to make good predictions about their behavior when searching, capturing and returning to land and selling their catches.

Monetary return was a good currency by which to evaluate decisions in this small-scale shrimp fishing setting. This is valuable information given the lack of data concerning the economic motivations underlining fishermen's behavior (Petreire *et al.*, 2006). As long as fishermen are exploring 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 such as the ones that are still widespread in Brazil have proven to be inefficient at bringing together social and environmental improvements. In conclusion, the methodological approach used in this work can reveal less desirable fishing grounds that could be used as

locally more acceptable refuge areas (Aswani, 1998b), though management strategies must be carefully analyzed when the technology has many side effects.

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Table 1 - Fishermen and their boats. Data reported by 20 trawler owner fishermen interviewed in São Francisco (São Sebastião, SP). Average, Coefficient of Variation (CV = Standard Deviation / Average) and Minimum and Maximum values are represented for each variable in the columns.

	Fisher Age	Years fishing	Boat length	Trawl length
Average	41.25	28.44	9.97	11.96
SD	7.66	8.52	3.00	4.19
Minimum	32.00	12.00	7.70	5.00
Maximum	56.00	42.00	18.50	22.00

Table 2 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	<i>Xiphopenaeus kroyeri</i>	Penaeidae	3.29	42.90	2,903.00
White shrimp	<i>Litopenaeus schmitti</i>	Penaeidae	7.19	21.41	1,448.65
Argentine red shrimp	<i>Pleoticus müelleri</i>	Solenoceridae	1.80	9.24	625.00
Argentine stiletto shrimp	<i>Artemesia longinaris</i>	Penaeidae	1.50	2.50	169.00
Total (shrimp)				76.04	5145.65
Fish					
Mixing of small fishes (bycatch)	-----	various	0.60	18.22	1,233.00
Brazilian codling	<i>Urophycis</i> spp.	Phycidae	1.50	3.40	230.00
Ray	-----	-----	1.20	1.29	87.50
Southern Weakfish	<i>Cynoscion jamaicensis</i>	Sciaenidae	1.50	0.41	28.00
Weakfish (pescada)	<i>Cynoscion</i> spp.	Sciaenidae	3.59	0.36	24.30
Southern kingcroaker	<i>Menticirrhus americanus</i>	Sciaenidae	0.60	0.10	7.00
Whitemouth croaker	<i>Micropogonias furnieri</i>	Sciaenidae	1.20	0.01	1.00
Total (fish)				23.80	1,610.80
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		6,766.76

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.)

Table 3 . Shrimp fishing trips. Average, Coefficient of Variation (CV = Standard Deviation / Average) and Minimum (Min) and Maximum (Max) values for fishing trips data. N = 77 fishing trips.

	Travel time (min)	Round trip time (min)	Fishing time (min)	Number of trawlings	Time of each trawling (min)	Total trawling time (min)	Gross return (Kg)	Gross return (US)
Average	93.90	1,228.60	1,040.8	5.80	107.40	629.0	87.90	293.22
CV	0.64	0.81	0.90	0.68	0.21	0.82	1.00	1.12
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

Round trip time is the total amount of time spent from the very moment of the departure until the arriving. Fishing time is the total round trip time minus the travel time multiplied by 2 (travel to and from the fishing spot); US 1 = R\$ 1.67 (average between 04/16 and 05/07 of 2008)

Table 4 - 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 = 68 shrimp fishing trips for the travel time regressions and N = 73 trips involving trawling time variable.

Regression (Y, X)	Equation (Y=a +bX)	r² (%)	p	Df
Trawl.time, Tr.time	$Y = 3.4044 + 0.5540X$	33.69	< 0.01	67
Ret (Kg), Tr.time	$Y = -0.5539 + 0.9075X$	33.17	< 0.01	67
Ret (\$), Tr.time	$Y = 0.8646 + 0.9661X$	38.56	< 0.01	67
Ret (Kg), Trawl.time	$Y = -2.5470 + 1.0643X$	48.88	< 0.01	72
Ret (\$), Trawl.time	$Y = -1.7405 + 1.2048X$	65.82	< 0.01	72



Figure 1. Fishing grounds used more than three times during the study by shrimp fishermen from São Francisco (São Sebastião-SP). Black ellipses represent the fishing grounds whose names are close to them. Number of fishing events in each ground is shown inside parenthesis. São Sebastião, Ilhabela and Caraguatatuba are the three municipalities that encompass the whole fishing area used by shrimp fishermen of São Francisco neighborhood. Other fishing grounds 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.

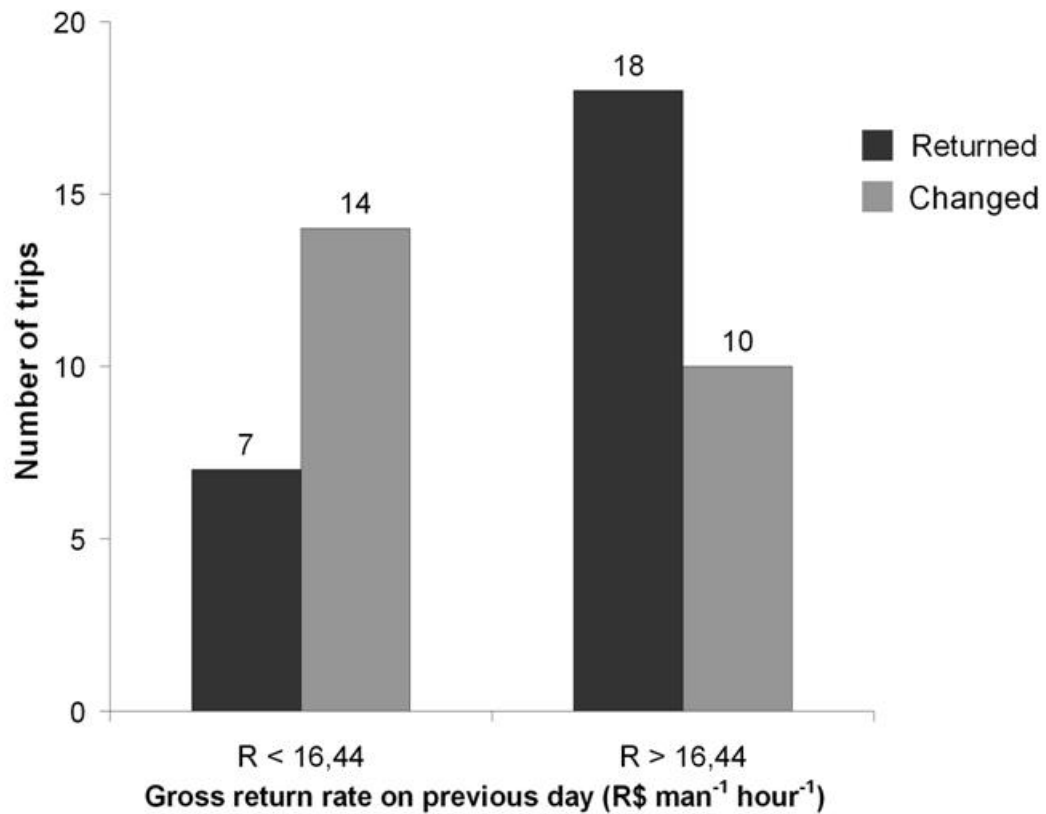


Figure 2. Number of fishing trips in which the fishermen returned to (dark gray bars) or changed (light gray bars) the fishing spot based on the previous day capture. In the first situation, gross return rate was below the average return rate of all spots in the environment (R\$16.44/hour/man). In the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

CONCLUSÃO GERAL

Três importantes aspectos da pesca de arrasto de camarão foram elucidados neste trabalho: 1) as decisões dos pescadores sobre a utilização dos pontos de pesca são bastante dinâmicas e puderam ser previstas com base na taxa de retorno financeiro obtida na última viagem de pesca; 2) os pescadores estão explorando o recurso local da forma mais eficiente possível, visando o retorno a curto prazo, o que pode ser um indício de que os recursos podem ser exauridos à longo prazo; e 3) há implicações teóricas e metodológicas do uso de modelos ecológicos que podem ajudar na elaboração de estratégias de manejo mais adequadas às realidades locais. Os três aspectos serão discutidos a seguir.

A utilização de variáveis econômicas, como o retorno financeiro, para prever as motivações e decisões dos pescadores de pequena escala é rara nos estudos de pesca, apesar de serem importantes indicadores desta atividade (Petriere Jr. et al., 2006). Os resultados obtidos neste trabalho mostram que a decisão do pescador sobre qual ponto utilizar, pode ser prevista utilizando a taxa de retorno financeiro obtida na viagem de pesca anterior. Os pescadores preferem voltar para pontos de pesca nos quais a taxa de retorno bruto (R\$ hora⁻¹homem⁻¹) da última viagem de pesca foi maior do que a taxa de retorno bruto média dos pontos de pesca utilizados naquela região. Apesar de que possivelmente outras variáveis também atuem nesta tomada de decisão, como por exemplo, a informação da captura de outros pescadores, tais resultados corroboram a hipótese levantada por vários estudos de que o sucesso da última captura interfere na decisão sobre qual ponto de pesca (ou mancha de recurso) utilizar. A escala de análise diária foi essencial para a obtenção deste resultado.

De acordo com as previsões da TFO, quanto mais longa a viagem até o ponto de pesca, maior o tempo que o pescador permanece arrastando no local e, conseqüentemente maior é o retorno obtido (financeiro e em biomassa). Este resultado mostra que os pescadores estão otimizando, ou seja, estão maximizando o retorno em curto prazo, extraindo o recurso da forma mais eficiente possível. Se para que os recursos sejam conservados é necessário que os indivíduos reduzam o seu retorno a curto prazo, este comportamento levará à exaustão do camarão a longo prazo. Usando um modelo simplista que não leva em conta as diferenças na biologia das espécies de presa, Joshi e Gadgil (1991), mostraram que o uso de refúgios (áreas onde o recurso não é explorado), desde que de tamanho adequado e permitindo o livre cruzamento das populações de recurso, pode prevenir tal exaustão mesmo quando o comportamento dos pescadores é equivalente ao observado neste trabalho. É evidente que uma proposta de manejo adequada não deve basear-se somente no uso dos refúgios e sim levar em conta as especificidades sociais e ambientais em escala local do sistema em questão. Mesmo assim, a proposta de refúgio, associada a outras medidas pode ser uma sugestão válida.

A metodologia empregada neste estudo é capaz de acessar quais pontos de pesca são mais utilizados (preferidos) e quais são menos utilizados (Figura 1). Aswani (1998b) mostrou que o fechamento de áreas para refúgio é localmente mais aceito quando ocorre em áreas menos desejadas pelos pescadores. Outros estudos, tais como os de Mamirauá, mostram que podem ser áreas muito utilizadas. Para isto, o pescador tem que fazer parte do manejo, entender o porquê de fechar ou fazer a rotação de áreas de pesca, de forma que até ele mesmo venha a sugerir que importantes pontos de pesca sejam refúgios, ainda que temporários. Tais informações devem ser levadas em conta no momento da elaboração de estratégias de manejo local mais eficazes. Entretanto, deve-se ter em vista os outros

aspectos negativos provocados pela técnica de arrasto de fundo, como o rejeito (*by-catch*) de espécies de menor valor e a destruição de hábitat.

Conclui-se, então, que os modelos gerados pela TFO mostraram-se úteis na compreensão do comportamento dos pescadores de arrasto de camarão de São Francisco. Entretanto, os modelos de otimização que se propõem a compreender fenômenos biológicos não podem ser encarados como algo fixo, nos quais, apenas a comparação dos comportamentos observados e esperados representa o resultado do trabalho. Como qualquer modelo de estudo, os modelos de forrageio ótimo devem ser utilizados como simplificações da complexidade do mundo real e, como tal, devem fornecer explicações aproximadas da verdadeira natureza do comportamento. Desta forma, o objetivo dos estudos de otimização de comportamento não é demonstrar que organismos otimizam, mais do que isso, eles são tentativas de explicar a complexidade da vida (Mayard Smith, 1978). Deve-se sempre lembrar a frase escrita por MacArthur e Pianka (1966) na primeira página de seu artigo: “mais do que algo certo, as teorias de otimização são hipóteses a serem testadas”.

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ANEXO 1 – Ficha de acompanhamento de desembarque

Primeira abordagem

Ficha n°: _____ Data: ___/___/___
Nome: _____ Pescador tempo integral? _____
Embarcação: _____ Comprimento: _____ (m)
Largura da rede: _____ (m) Malha: _____

Todos os desembarques

Ficha n°: _____ Data: ___/___/___
Origem: _____ Número tripulantes: _____
Hora saída: _____ Tempo viagem: _____
Hora chegada: _____
Local de pesca: _____
Número arrastos: _____ Tempo de arrasto: _____
Local pesca anterior: _____

Pescado capturado (espécie)	Peso (Kg)
_____	_____
_____	_____
_____	_____
_____	_____

Obs.: _____