Luciana Cavalcanti Maia Santos

**A pesca nos manguezais no Estuário do Rio São
Francisco: uma abordagem sócio-ecológica com ênfase
no caranguejo *Ucides cordatus* (Linnaeus, 1763)**

**Mangrove fisheries in the São Francisco River Estuary
(Northeastern, Brazil): a socio-ecological approach with
emphasis on the mangrove crab *Ucides cordatus*
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São Paulo

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CAPÍTULO 1

Introdução Geral

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Introdução Geral

1. Manguezais como um exemplo de sistema sócio-ecológico complexo

Manguezais são ecossistemas costeiros, de transição entre os ambientes terrestre e marinho, característicos de regiões tropicais e subtropicais e sujeitos ao regime das marés (Schaeffer-Novelli, 1991). A cobertura vegetal é constituída de espécies vegetais lenhosas típicas (angiospermas), além de micro e macro algas (criptógamas) adaptadas à flutuação de salinidade e caracterizadas por colonizarem sedimentos predominantemente lodosos, com baixos teores de oxigênio (Schaeffer-Novelli, 1995). Os manguezais incluem aproximadamente 73 espécies vegetais e híbridos, pertencentes a 20 famílias, com ocorrência de maior diversidade vegetal nos manguezais do Indo-Oeste Pacífico que do Atlântico e Leste Pacífico (Spalding et al., 2010).

Essas florestas de entre-marés ocupam aproximadamente de 60 a 75% das regiões costeiras (sub) tropicais, encontram-se entre os mais produtivos ecossistemas da biosfera (Kjerfve, 1990), ocorrendo em 123 países e ocupando globalmente 152.000 km², o que equivale a metade da área das Filipinas ou um quarto de Madagascar (Spalding et al., 2010). Isto torna o manguezais um tipo de floresta relativamente rara globalmente, pois são restritas às zonas costeiras tropicais e subtropicais, restringidas por temperaturas frias, e exibindo maiores abundâncias e diversidade ao longo das costas úmidas quentes, áreas estuarinas e deltas de rios (Spalding et al., 2010).

O Brasil apresenta a terceira maior área de mangue do planeta (1,114,398.60 ha), abrigando 7% dos manguezais do mundo e 50% dos da América Latina (FAO, 2007; Magris e Barreto, 2010; Giri et al., 2011). O ecossistema encontra-se distribuído ao longo da costa

brasileira, desde o extremo norte, no Rio Oiapoque (Amapá) até o sul, em Laguna (Santa Catarina) (Schaeffer-Novelli et al., 1990). Grande parte dos manguezais brasileiros (83%) ocorre no setor da costa de macromarés (4°N a 3°S), região norte do país, onde se encontra a maior faixa de mangue contínua do mundo (Magris e Barreto, 2010; Nascimento, 2013). Na costa de meso-marés (3° a 15°S), região nordeste, ocorrem cerca de 10,6% dos manguezais brasileiros e o restante (6,4%) está distribuído na costa de micro-marés (15° a 34°S), nas regiões sudeste e sul (Magris e Barreto, 2010).

Apesar de serem florestas relativamente raras e de possuírem baixo número de espécies vegetais, florestas de mangue geram, por ano, pelo menos US\$ 1,6 bilhões em serviços ecossistêmicos e fornecem os meios de subsistência de populações humanas costeiras nas regiões (sub)tropicais do mundo (Polidoro et al., 2010; Spalding et al., 2010). É amplamente reconhecido e documentado o papel dos manguezais como geradores de uma gama de funções ecológicas, econômicas, sociais e ambientais em nível local, nacional e global. Essas funções incluem: conservação de uma diversidade biológica única, sustentação da pesca costeira exercendo função de berçário dos recursos pesqueiros, fonte de recursos naturais e econômicos para comunidades humanas tradicionais, proteção da linha de costa contra tsunamis, tempestades e erosão, habitat para uma gama de animais marinhos e terrestres e importante fonte de fixação de carbono (Schaeffer-Novelli, 1995; Barbier, 2000; FAO, 2007; Walters, 2008; Barbier et al., 2013).

Embora seja reconhecida a importância dos manguezais, pressões de tensores antrópicos são persistentes (Mohamed et al., 2009), resultado em perdas que ocorrem em taxas anuais de 1 a 2%, indicando a possibilidade de se enfrentar, dentro dos próximos 100 anos, um mundo privado dos serviços dos manguezais (Valiela et al., 2001; Alongi, 2002; Duke et al., 2007). Estudos estimam que entre 1980 e 2005 ocorreu uma perda de 20% (3,6 milhões ha) dos manguezais do mundo, principalmente devido ao desmatamento dos

manguezais pela pressão demográfica e para criação de camarões em cativeiro (FAO, 2007). Infelizmente o Brasil segue essa tendência mundial e embora a conservação dos manguezais desse país seja assegurada por várias normas legais, como o Código Florestal Brasileiro, Resoluções CONAMA e o Plano Nacional de Gerenciamento Costeiro, uma variedade de tensores antrópicos afeta o ecossistema, gerando perdas estimadas em mais de 50.000 ha (Schaeffer-Novelli, 1991; FAO, 2007; Santos et al., 2014).

Vale ressaltar que não apenas o ecossistema manguezal está altamente ameaçado pelos impactos e pressões antrópicas, mas também as comunidades humanas dependente de seus recursos, juntamente com o seu conhecimento sobre o manguezal, também estão ameaçados de extinção, uma vez que ainda estão sub-representados como tema de investigação científica (Dahdouh-Guebas, et al., 2006).

Ao se considerar a alta dependência econômica e de subsistência de populações humanas sobre os recursos naturais extraídos e explorados nos manguezais, se reconhece que essas atividades caracterizam os manguezais como importantes sistemas sócio-ecológicos complexos das zonas costeiras tropicais e subtropicais. Todos os recursos naturais utilizados pelas sociedades humanas constituem sistemas sócio-ecológicos (SSE) complexos, os quais são compostos de múltiplos subsistemas e variáveis internas dentro destes subsistemas em vários níveis (Ostrom, 2009; Figura 1). Por exemplo, em um SSE complexo, subsistemas tais como o sistema de recursos (por exemplo, a pesca em áreas de manguezal), as unidades de recursos (peixes), usuários (pescadores), e sistemas de governança (organizações e regras que regulamentam a pesca naquela costa) são relativamente separáveis mas interagem para produzir resultados a nível do SSE, que por sua vez se retro-alimentam e voltam a afetar os subsistemas e respectivos componentes, bem como outros SES adjacentes (Ostrom, 2009; Figura 1).

Portanto, a pesca constitui um sistema SSE complexo, formado pela interação desses três sistemas: 1) o natural, que envolve o recurso pesqueiro, o ecossistema e o ambiente biofísico; 2) o humano, o qual abrange os pescadores, os consumidores, o setor de mercado/indústria, as comunidades pesqueiras e o ambiente social econômico e cultural, e por fim 3) o manejo, que inclui os planos, políticas, manejo, desenvolvimento e pesquisa da pesca (Charles, 2001). O estudo de SSE complexos fornece compreensões sobre a inter-relação de diferentes campos, como o natural/biológico, social, econômico e de manejo, gerando uma compreensão mais profunda da dinâmica de SSE que é extremamente relevante para a conservação e gestão desses sistemas (Berkes et al. 2003; Ban et al., 2013). O desenvolvimento de políticas de gestão sustentável que contemplem também as necessidades de subsistência da população local, é uma alta prioridade, assim estudos sócio-ecológicos sobre manguezais estão se tornando cada vez mais utilizados (Dahdouh-Guebas, et al. 2006).

Dentre a diversidade de recursos naturais extraídos nos manguezais, desde os florestais como taninos, resinas, mel, madeira e medicamentos; os recursos pesqueiros, como peixes, crustáceos e moluscos são indiscutivelmente reconhecidos como os mais importantes economicamente para as populações humanas desses sistemas sócio-ecológicos complexos (Walters et al, 2008; Rönnbäck, 1999, Barbier et al., 2013). Correlações positivas foram demonstradas entre a cobertura de manguezal e desembarques de pescado (Camacho e Bagarinao, 1987; Rönnbäck, 1999), assim, estima-se que dois terços das comunidades pesqueiras artesanais do mundo dependem da existência de manguezais (FAO, 2003, Wielgus et al. 2010).

Figura 1. Subsistemas fundamentais que constituem um sistema sócio-ecológico complexo (extraído de Ostrom, 2009).

A pesca artesanal no Brasil utiliza 70% da mão de obra e atinge cerca de 30% da produção da pesca marinha nacional (IBAMA, 1993a, 1993b, Mendonça e Pereira, 2010). A maioria da pesca artesanal brasileira está baseada em espécies estuarinas ou sobre aqueles que passam a maior parte do seu ciclo de vida em sistemas estuarinos, especialmente em áreas de manguezal (Schaeffer-Novelli e Cintron-Molero, 1999; Pinheiro et al., 2008, Duarte et al., 2014). Vários estudos documentam a pesca de diferentes recursos dos manguezais do Brasil, incluindo uma variedade de peixes, caranguejos, moluscos e camarões, tanto com relação à aspectos de exploração (e.g. Diele et al., 2005; Mendonça e Pereira, 2009; Mendonça e Machado, 2010; Duarte et al., 2014), produtivos (e.g. CEPENE, 1999, 2000, 2001, 2002, 2003, 2008) e etnobiológicos (e.g. Diegues, 1999; Nishida et al. 2004, 2006a, 2006b; Souto, 2006, 2008; Souto e Martins, 2009; Firmo et al., 2012; Magalhães et al., 2012).

2. O caranguejo *Ucides cordatus* (Linnaeus, 1763): aspectos biológicos, ecológicos, etnoecológicos e a pesca

O caranguejo *Ucides cordatus* (Linnaeus, 1763) pertence ao filo Arthropoda, subfilo Crustacea, ordem Decapoda, infraordem Brachyura e família Ocypodidae (Melo, 1996; Pinheiro e Fiscarelli, 2001; Brasil, 2011). Em revisão dos crustáceos braquiúros, a família Ocypodidae foi subdividida em quatro subfamílias, sendo o gênero *Ucides* alocado na subfamília Ucidinae (Stevcic, 2005), entretanto, Ng et al. (2008) encontraram indícios suficientes para a criação de uma nova família (Ucididae), que tem encontrado grande aceitação científica (Brasil, 2011). O gênero *Ucides* é caracterizado por possuir órbitas profundas, mas não muito maiores que os olhos; distância interorbital um pouco maior do que a metade da largura da carapaça; antênulas oblíquas; epistoma pequeno mas proeminente; e pernas fortes (Bright e Hogue, 1972, Brasil, 2011). A espécie *Ucides cordatus* é restrita às costa oeste das Américas, ocorrendo ao longo dos manguezais desde a Flórida (EUA) até Santa Catarina (Brasil) (Melo, 1996).

Ucides cordatus é um caranguejo semiterrestre que ocorre apenas na região compreendida entre os níveis de maré baixa e alta, exclusivamente no ambiente estuarino associado a vegetação característica dos manguezais, onde escava galerias de até 2 m de profundidade no sedimento desses ecossistemas e possui hábitos noturnos (Costa, 1979; Alcantara-Filho 1978; Pinheiro e Fiscarelli, 2001, Schmidt, 2006). *Ucides cordatus* apresenta crescimento lento e pode alcançar uma idade de 10 a 11 anos, atingindo maturidade entre 2 a 3 anos (Pinheiro et al. 2005; Diele et al., 2005). Esse caranguejo é considerado uma espécie-chave do ecossistema manguezal por sua alta biomassa, o seu papel na ciclagem de nutrientes e na estrutura trófica destes ecossistemas (Koch e Wolff 2002; Schories et al. 2003; Nordhaus et al. 2006), além de ser um dos componentes mais importantes da fauna dos manguezais brasileiros (Koch, 1999; Pinheiro e Fiscarelli, 2001).

Além dessas funções ecológicas, *U. cordatus* desempenha importante função socioeconômica para a pesca artesanal costeira no Brasil, onde sua captura é uma das atividades extrativistas mais antigas em áreas de manguezais (Pinheiro e Fiscarelli, 2001; Souto, 2007). Trata-se de um recurso pesqueiro abundante, de grande aceitação comercial e que contribui para a geração de emprego, renda e subsistência em comunidades pesqueiras de estuários (Souto, 2007), especialmente na costa norte e nordeste brasileira, onde se destaca como um dos principais produtos explorados nos manguezais (e.g. Fiscarelli e Pinheiro, 2002; Glaser, 2003; Glaser e Diele 2004, Alves e Nishida, 2003; Alves et al 2005; Souto, 2007; Firmo et al. 2011, Magalhães et al., 2012; Cortês et al., 2014). As principais áreas de ocorrência e extração do *U. cordatus* ocorrem em dez estados brasileiros: Pará, Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe e Bahia (IBAMA, 1994).

As comunidades locais que vivem próximas aos manguezais e dependem de recursos oriundos desse ambiente desenvolveram ao longo do tempo um amplo conhecimento acerca dos componentes bióticos e abióticos que integram esse ecossistema (Alves e Nishida, 2002). Embora os manguezais venham sendo estudados sistematicamente em muitas partes do mundo, tópicos avaliando sua importância como meio de subsistência e fonte de renda para populações locais ainda são limitados (Satyanarayana et al., 2012). No Brasil, estudos que consideram o saber tradicional têm se intensificado nos últimos anos, notadamente os que incluem o etnomanejo de habitats (Diegues et al., 1999; Alves e Nishida, 2002). Para o caranguejo *U. cordatus* têm-se registrado um amplo etnoconhecimento acerca de sua biologia e ecologia, tais como ciclo de vida, diferenciação sexual, tamanho corporal, habitat, comportamento, reprodução, métodos de captura, ecologia trófica, além de práticas locais de conservação e manejo (e.g. Alves e Nishida, 2003; Souto, 2007; Nordi et al., 2009; Firmo et al. 2011, Magalhães et al., 2012; Nascimento et al., 2012; Cortês et al., 2014). Atualmente

vários pesquisadores veem demonstrando interesse não apenas sobre a biologia da espécie, mas também sobre os aspectos sociais, econômicos, culturais e ecológicos relacionados à pesca do caranguejo *U. cordatus* (Souto, 2007). A estrutura e dinâmica populacional de *U. cordatus* nos manguezais do Brasil também tem sido objeto de estudo (e.g. Glaser e Diele 2004, Alves et al. 2005; Hattori, 2006; Schmidt, 2006; Wunderlich et al., 2008; Sandrino e Lana, 2011), o que é muito importante em termos de dados para avaliação do estoque e manejo da pesca do recurso.

Entretanto, estimativas de estoque do caranguejo-uçá são raras, e alguns autores indicam um possível esgotamento do recurso, ao longo do litoral brasileiro, pela sobre-exploração (Botelho et al., 2001; Jankowski et al., 2006; Brasil, 2011) aliada à perda e degradação de habitats de manguezais e a doença do caranguejo letárgico que causou mortalidades em massa que dizimaram estoques locais (Boeger et al 2005, Diele et al., 2005; Alves e Nishida, 2003; Firmo et al., 2011). Esse cenário destaca a necessidade de estudos que contribuam a implementação de medidas de manejo para o uso sustentável e conservação da espécie.

3. Ferramentas de análise espacial para estudo de sistemas sócio-ecológico complexos

O sensoriamento remoto é a ciência de obter informação sobre um objeto, área ou fenômeno pela análise sem contato físico com os mesmos, baseando-se somente na interação da radiação eletromagnética e os diferentes materiais da cena (Lillesand et al., 2008; Novo, 2011). Os sensores são dispositivos idealizados para captar a energia eletromagnética proveniente de objetos, fenômenos e feições da superfície terrestre como: vegetação, solos, rochas, corpos d'água, casas, edifícios e rodovias, e transformá-la em dados, imagens ou outros produtos interpretáveis pelo homem (Luchiari et al., 2009). Para a obtenção de informações sobre o objeto, área ou fenômeno de investigação, imagens produzidas por

sensores remotos, tais como: fotografias aéreas, imagens obtidas por sensores ópticos multiespectrais (usualmente referidas como imagens de satélites) e imagens de radar, são interpretadas utilizando técnicas de análise visual e/ou de processamento digital (Jesen, 2009). Nessa etapa, as imagens são integralizadas, processadas e analisadas em programas de geoprocessamento ou SIGs (Sistemas de Informação Geográfica), o que permite a geração e obtenção de novas informações ou mapas derivados dos dados originais, que podem ser incorporados à dados complementares de campo (por exemplo: diversidade biológica, tipos vegetacionais, abundância de fauna estrutura, populacional de uma espécie), como também dados sociais e econômicos (Florenzano, 2002). Em termos de recursos naturais os SIGs podem servir para o planejamento e proteção ambiental, gestão de recursos naturais e estudos de impacto sobre o meio ambiente (Silva, 2003).

A análise multicritério é uma técnica de geoprocessamento implementada em SIGs que constitui um método dirigido à tomada de decisão bastante aplicado na gestão ambiental (Santos, 2004) e vem apresentando representatividade também na gestão dos recursos pesqueiros (Andalecio, 2010). A análise multicritério destina-se a investigar um número de possibilidades frente à múltiplos critérios e prioridades conflitantes e permite incorporar, sistematicamente, aspectos sociais, econômicos, técnicos e ambientais (Santos, 2004). A avaliação multicritério consiste basicamente em classificar e alocar áreas mais apropriadas para determinado uso (objetivo) e espacializar os dados através da produção de mapas indicativos de aptidão (Eastman, 2012). Essa técnica faz uso de informações espacializadas em formas de mapas e imagens, portanto a utilização de ferramentas de sensoriamento remoto e de outras técnicas de geoprocessamento é imprescindível para a geração dos mapas dos fatores que compõem a análise e mapas finais de aptidão.

Métodos multicritério permitem lidar com informações mistas de diferentes origens metodológicas, tanto quantitativas como qualitativas, e em diferentes escalas, (Andalecio,

2010). Essa análise demonstra ampla utilidade em muitas questões ambientais e conservacionistas que conectam questões econômicas, biológicas, sociais, culturais e medidas técnicas de gestão (Abu-Taleb, 2000; Makowski et al., 1996). Esse tipo de integração de várias questões ressalta a potencialidade desse tipo de análise para o estudo de SSE complexos, pois permite considerar a multidimensionalidade e complexidade dos diferentes subsistemas que constituem os SSEs.

As vantagens de se utilizar análises multicritério são resumidas por (Andalecio, 2010) nos seguintes tópicos: útil para melhorar o processo de tomada de decisões, levando à aceitação pública das opções sugeridas; aplicabilidade nas decisões que envolvem vários autores, proporcionando uma avaliação transparente, estruturada, rigorosa e objetiva de opções; ferramenta de resolução de divergências que avalia o progresso de um determinado objetivo, reduzindo o nível de complexidade de informações; auxilia no equilíbrio de demandas ambientais conflitantes de conservação ambiental e desenvolvimento com relação à alocação de água e desenvolvimento costeiro.

Portanto análises multicritérios têm sido aplicadas para otimização na seleção de políticas e ações para remediação de áreas contaminadas, redução de contaminantes dentro de ecossistemas aquáticos, otimização do uso e gestão da água, recursos naturais e costeiros (Huang et al., 2011). Para pesca o uso dessa técnica proporciona um equilíbrio e permite integrar os vários componentes dessa atividade, abrangendo aspectos ecológicos, biológicos, sociais, econômicos e objetivos institucionais de manejo e conservação (Andalecio, 2010).

4. Área de estudo: o estuário do Rio São Francisco, zona costeira de Sergipe, Nordeste do Brasil

A zona costeira do Estado de Sergipe, localizada na região nordeste do Brasil, entre a foz do Rio São Francisco, ao norte ($10^{\circ}30'S / 36^{\circ}25'W$), e a foz do Rio Real, ao sul ($11^{\circ}25'S / 37^{\circ}20'W$), possui uma linha de costa com extensão de aproximadamente 163 km e área de 1.200 km² (ADEMA, 1984; Carvalho, 2004) (Figura 2). Essa zona costeira apresenta uma diversidade de aspectos físicos, biológicos e socioeconômicos, onde ocorrem extensas áreas de manguezais associadas aos seis estuários presentes em sua costa (Santos, 2010, Figura 2). Dentre esses estuários, o do Rio São Francisco integra o extremo litoral norte de Sergipe, encontra-se localizado na divisa entre esse estado e Alagoas, e dista aproximadamente 90 km da capital Aracaju.

A área de estudo corresponde à parte sul do Estuário do Rio São Francisco (Estado de Sergipe) (Figura 3), local onde ocorrem os manguezais, e abrange cerca de 192,35 km² e faz parte dos municípios de Brejo Grande e Pacatuba. Cerca de 93% (178,8 km²) da área de estudo é ocupada por cobertura natural, tais como: restingas (147,3 km², 77%), manguezais (30,1 km², 15,7%) e apicuns (1,4 km², 0,7%), enquanto 7% (13,6 km²) é ocupada por atividades humanas como a aquicultura (4,6 km², 2,4%) e cultivos de coco e arroz (9 km², 4,7%) (Santos et al., 2014, Figura 3).

O clima da região é do tipo tropical semi-úmido, caracterizando-se por temperatura média de 25°C, com amplitude inferior a 4°C entre as médias, regime de ventos predominantemente vindos de NE e ESE, e pluviosidade com duas estações marcadas: uma mais chuvosa, entre os meses de abril e agosto, e outra seca, entre setembro a março (Medeiros, 2003). A área é sujeita a um regime de mesomarés, com marés semi-diurnas (duas baixamares e duas preamares) (Semensatto, 2006).

Figura 2: Zona costeira de Sergipe (Extraído de Carvalho, 2004, Fonte: Mapa hidrográfico de Sergipe, 1974. Adaptado de Amâncio, 2001).

A área de estudo é caracterizado por uma notável falta de infra-estrutura, tais como estradas pavimentadas, hospital, centro de saúde, escolas, lojas comerciais e serviços em geral. Os habitantes são populações locais compostas por moradores nativos cuja renda e subsistência depende de atividades agrícolas, aquicultura e principalmente da pesca em áreas de manguezal (CEPENE, 2008), com destaque para o município de Brejo Grande que é responsável pelo desembarque de quase toda a produção de *Ucides cordatus* do estado (Brasil, 2011). Essas populações ocorrem ao longo de oito povoados distribuídos paralelamente à linha de costa e aos manguezais (Figura 3).

Figura 2. Mapa de uso e cobertura do solo da porção sul do Estuário do Rio São Francisco, Estado de Sergipe.

Desde 2004, a região do Estuário do Rio São Francisco faz parte de uma Área de Proteção Ambiental Estatal denominada "APA - Litoral Norte", criada pelo decreto n.º 22.995 de 09 de novembro de 2004, cujos objetivos incluem: promoção do desenvolvimento econômico-social da área, voltado às atividades que protejam e conservem os ecossistemas ou processos essenciais à biodiversidade, à manutenção de atributos ecológicos e à melhoria da qualidade de vida da população (Sergipe, 2004). Entretanto, o contexto atual de pobreza, carência de empregos e alternativas para geração de renda, a diminuição dos recursos pesqueiros e o desmatamento de manguezais para a carcinocultura são obstáculos para alcançar a sustentabilidade estipulada por essa APA.

5. Objetivos

O presente estudo considera a estrutura metodológica de Ostrom (2009) para estudo de sistemas sócio-ecológicos complexos, considerando a análise da pesca nos manguezais do estuário do Rio São Francisco, com ênfase no caranguejo *Ucides cordatus*. Baseado nessa metodologia, o sistema do recurso constitui a região do estuário do Rio São Francisco e seus manguezais, a unidade de recurso constitui os recursos pesqueiros dos manguezais com ênfase no caranguejo *Ucides cordatus*, os usuários são os pescadores e catadores de moluscos e caranguejos; e os sistema de governança incluem todas as leis, portarias, normativas e planos de manejo que orientam o uso dos recursos pesqueiros e da APA Litoral Norte. Nesse contexto os objetivos do presente estudo são:

- objetivo 1: caracterizar o uso de recursos pesqueiros dos manguezais, com importância econômica, pelas das populações humanas do estuário do Rio São Francisco, bem como as percepções dessas populações sobre mudanças e impactos que ocorreram na produção desses recursos durante os últimos 13 anos e suas perspectivas para o desenvolvimento local e melhoria da qualidade de vida

- objetivo 2: caracterizar o conhecimento local (etnoconhecimento) das populações humanas desse estuário acerca da ecologia, biologia e práticas conservacionistas e de pesca do caranguejo *U. cordatus*

- objetivo 3: caracterizar a estrutura populacional do caranguejo *Ucides cordatus* nos manguezais do estuário do Rio São Francisco e avaliar o potencial desses manguezais para a pesca desse recurso

- objetivo 4: discriminar, mapear e quantificar as áreas de manguezal mais aptas para a pesca e para a conservação do *Ucides cordatus* nos manguezais desse estuário

- objetivo 5: fornecer subsídios para implementação de uma pesca sustentável do *Ucides cordatus* no Brasil, e especialmente no estuário do Rio São Francisco, e para o Plano Nacional de Gestão para o Uso Sustentável do Caranguejo-uçá

A presente tese foi estruturada em seis capítulos, dos quais o primeiro é uma introdução geral sobre os assuntos a serem abordados com os respectivos objetivos, aqui apresentados. O segundo, terceiro, quarto e quinto capítulos são redigidos em inglês em formato de manuscrito científico, como sugerido pelo programa de pós-graduação. O capítulo 2: "Mangrove fisheries as base of subsistence economy in the São Francisco River Estuary (Northeastern Brazil): considerations for local management", contempla o objetivo 1. O capítulo 3: "Local knowledge and capture practices of the most exploited mangrove crab *Ucides cordatus* in the São Francisco River Estuary (Northeastern Brazil)", corresponde ao alcance do objetivo 2. O capítulo 4: "Population status and fishery potential of the mangrove crab (*Ucides cordatus*) in the São Francisco River Estuary (Northeastern Brazil)" atende o objetivo 3. E por fim, o capítulo 5: "Multi-criteria evaluation for the conservation and fishery of the mangrove crab *Ucides cordatus*: a case study in the São Francisco River Estuary (Northeastern Brazil)" consideram os objetivos 4 e 5. O capítulo 6 corresponde à uma discussão integrada e síntese dos principais resultados obtidos nos capítulos anteriores e conclusões formuladas.

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CAPÍTULO 2

**Mangrove fisheries as base of subsistence economy in the
São Francisco River Estuary (Northeastern Brazil):
considerations for local management**

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Abstract

Mangroves are socio-ecological systems which support important small-scale fisheries along the world's (sub) tropics coasts. In Northeastern Brazil, the São Francisco River Estuary (10° 30' 27"S, 36° 23'45"W) comprises a significant mangrove area (30 km²) used by local human populations. Although the area is part of a sustainable use conservation unit, the poverty, decrease of fisheries resources, deforestation of mangroves for shrimp farming and lack of jobs and income source alternatives are constraints to achieve sustainability. This study characterized the use and perceptions of local communities on the mangrove fisheries shifts that occurred during the last 13 years and their perspectives for local development. Five villages were sampled during January 2013 and 48 inhabitants (16% of the human population) were interviewed by using structured questionnaires. Currently 90% of the interviewees are economically dependent on the mangrove fisheries, exploring 12 different types of fish, 4 types of crabs, 3 types of mollusks and shrimps. Average earnings per individual fisherman reaches less than 39 USD per week, being not fixed and usually lower. All communities indicated a decrease in the fishery yield of the resources, which demands management strategies for its rational use. The locals cited initiatives that would improve their livelihood as: creation of a fishery processing industry (98%), government support for farming oysters and fish (90%) and to buy motorized boats (88%), creation of a Sustainable Development Reserve (81%) and ecotourism (79%). Such activities seem to be alternatives for poverty alleviation and should be considered for local sustainable development. We conclude that mangrove fisheries constitute the main base of a local subsistence economy, demanding management efforts for the mangrove forest conservation and local socio-development.

Key-words: coastal wetland, fishing villages, resource use

1. Introduction

All humanly used resources are embedded in a complex, social-ecological systems (SESs) (Ostrom, 2009). Mangroves, coastal ecosystems distributed along the world's (sub) tropics, can be characterized as a good example of SESs, since their resources have been heavily traditionally used for food, timber, fuel, medicine and economic subsistence (Rönnbäck, 1999, Alongi, 2002, Walters et al., 2008). This ecosystem support diverse local fisheries including fishes, crustaceans (crabs, shrimps) and mollusks, which are source of income for traditional and deprived human communities (Rönnbäck, 1999, Walters et al., 2008, Satyanarayana et al., 2013; Santos et al., 2014). Positive correlations have been demonstrated between mangrove cover and municipal fisheries landings (Camacho and Bagarinao, 1987; Rönnbäck, 1999), thus, it is estimated that two-thirds of the world's fishing communities depend on the existence of mangroves (FAO, 2003, Wielgus et al. 2010).

Though the importance of mangrove ecosystems for human subsistence has been reported before (Rönnbäck, 1999; Saenger, 2002; Walters, 2003; Wattage and Mardle, 2005; FAO, 2007; Walters et al., 2008, Satyanarayana et al., 2013), research on the extent on which the livelihoods depend on certain resources is still lacking (Satyanarayana et al., 2013). Evaluation of the importance of mangroves for human communities and their knowledge about the ecosystem and fishery resources are important information for the local conservation and management as well as for the maintenance of these communities and fishery stocks (e.g. Diegues, 2000; Souto, 2006, 2007; Nordi et al., 2009; Firmo et al., 2012, 2011; Magalhães et al., 2012, Satyanarayana et al., 2013).

Brazil, with a coastal zone of approximately 8,500 km of extent (4° 30' N to 33° 44' S), shows the third largest mangrove area in the world (Asmus and Kitzmann, 2004; FAO, 2007; Magris and Barreto, 2010; Giri et al., 2011). In this country artisanal fishery is fundamentally relevant because this activity produces food, for commercial purposes and a

means of economic subsistence (Diegues, 2002, Nishida et al., 2006a). The bulk of Brazilian fishery is based on mangrove ecosystems whose species spend most of their life cycle in those environments (Vannucci, 2002; Nishida et al., 2006a). A diversity of fishery resources are exploited in Brazilian mangroves, such as fish (e.g. Souto, 2008a), mollusks (e.g. Souto and Martins, 2009; Nishida et al. 2004, 2006a, 2006b; Mendonça and Machado 2010) and crabs (e.g. Fiscarelli and Pinheiro, 2002; Alves and Nishida, 2002; 2003; Alves et al., 2005; Ferreira et al., 2009; Nordi et al., 2009; Firmo et al., 2012, 2011; Magalhães et al, 2011, 2012) .

Although various decrees and laws legally enforce the conservation and management of Brazilian mangroves, the ecosystem have been affected by a variety of anthropogenic activities (Santos et al., 2014), resulting in environmental changes and socio-economic impacts on the communities that depends on mangrove resources (e.g. Glasser, 2003). In this view, it is important to consider that the perception of environmental changes by local communities has proven valuable as a background to reconstruct historical use and impact on mangroves (Walters, 2003; Dahdouh-Guebas et al., 2004, 2005, Walters et al., 2008, Nfotabong-Atheull et al., 2011), serving as information and support for the local management and conservation efforts (e.g. Satyanarayana et al., 2013).

In Northeastern Brazil, the São Francisco River Estuary (10° 30' 27"S, 36° 23'45"W) comprises a significant mangrove area (30 km²) important for deprived human populations which depend on the fishery resources collected on the mangrove environment. Despite this, the importance of mangrove resources for these local populations is not well documented. Additionally, even though this area is part of a sustainable use conservation unit, the poverty, decrease of fisheries resources and deforestation of mangroves for shrimp farming are constraints to achieve sustainability. This study aims to characterize the use of economic important mangrove fishery resources by the human populations of the São Francisco River Estuary, their perceptions on the mangrove fisheries shifts that occurred during the last 13

years and their perspectives for local development. Based on this information, we pointed out some strategies important to be considered in the local management and for socio-ecological sustainability.

2. Material and methods

2.1. Study area

The São Francisco River is one of the most important Brazilian water resources and is considered the River of National Integration, draining seven states along its 2,863 km. The river basin (636,919 km²) is divided in four sub-regions from its nascent to its estuary: high, medium, sub-medium and low São Francisco (ANA, 2005, Figure 1a, 1b). The estuary of this river is located in the low sub-region, on the boundary of Sergipe and Alagoas States (10° 30' 27"S, 36° 23'45"W) in the Northeast of Brazil (Figure 1b, 1c).

The study area corresponds to the southern part of the São Francisco River Estuary (State of Sergipe) (Figure 1c) and covers approximately 192.35 km² and is part of the municipalities of “Brejo Grande” and “Pacatuba”. About 93% (178.8 km²) of the study area is occupied by natural cover such as: sandy coastal vegetation (147.3 km², 77%), mangroves (30.1 km², 15.7%) and intertidal flats (1.4 km², 0.7%), while 7% (13.6 km²) is occupied by human activities as aquaculture (4.6 km², 2.4%) and agriculture (9 km², 4.7%) (Santos et al., 2014). The climate in this region is Tropical Wet & Dry (Aw), according to the Köppen Climate Classification System.

Figure 1. (a) Map of South America and Brazil indicating the location of the São Francisco River basin (adapted from ANA, 2005). (b) The São Francisco River basin with its four divisions (adapted from ANA, 2005). (c) A close-up of the São Francisco River Estuary, the study area.

The study area is part of a State Environmental Protected Area (APA “Litoral Norte”), a Conservation Unit of sustainable use which was created in 2004, but still does not have a Management Plan (Sergipe, 2004, Santos et. al., 2014). This area is characterized by a remarkable lack of public infrastructure, such as paved roads, hospital, health centre, schools and commercial services. The inhabitants are distributed along eight small villages located parallel to the mangrove forests (Figure 1c) and they are deprived population composed of native residents showing low human development indices (0.584 and 0.550).

2.2 Data collection in the coastal villages

On January 2013 fieldworks were carried out in order to collect data about the use of economic important mangrove fishery resources (fish, crabs, shrimps and mollusks) by the human populations of the São Francisco River Estuary, their perceptions on the mangrove

fisheries shifts that occurred during the last 13 years and their perspectives for local development. By a set of eight coastal villages, we sampled five villages (Table 1, Figure 1c) which were chosen because they are the most important in terms of crab and fishery production in the region. The geographic coordinates of each village visited were recorded in a GPS (Global Positioning System, Garmin eTrex Venture HC). A native inhabitant acted as local mediator (e.g. Albuquerque et al., 2010a) to conduct us to the villages and to introduce the people to be interviewed. Only local specialists (e.g. Albuquerque et al., 2010a), i.e., people that use or used mangrove fishery resources were interviewed. Besides the aid of the local mediator, the snowball technique (Goodman, 1961) was also applied, in which the respondent indicates another one and so on.

We applied structured interviews (e.g. Alexiades, 1996; Albuquerque et al., 2010b) which were digitally recorded, filmed and photographed, when the interviewees allowed. The interviews were individual and collective in focal groups with number varying from two to six people. The interviews contained open-ended, yes/no and multiple choice questions. A total of 48 inhabitant were interviewed (16% of the local human population), with the participation of 35 men (73%) and 13 women (27%) whose ages ranged between 18 and 73. A presentation of the fieldwork group and the aims of the research were explained before starting each interview and the permission to record, film and photograph were ask for all participants. We were precluded from adopting a formal approach using interview consent forms, due to the poor level of organization of the communities and high illiteracy rates (e.g. Alves and Nishida, 2002, 2003; Alves et al., 2005, Firmo et al., 2011).

2.3 Analysis of data

All digitally recorded interviews were transcribed. The data were analyzed qualitatively, using the union model (Marques et al., 1991), in which all information collected

on the interviews were considered. After that, the responses were categorized and tabulated in Excel spreadsheets, in terms of number of people which gave each type of response, and its percentage in relation to the total of interviewees, and thus analysed quantitatively, and graphs were produced. The information provided by the participants was compared with those from the specialized academic literature, following ethnoscientific notions with a balance between emic and etic focused approaches (Sturtevant, 1964; Magalhães et al., 2012).

Table 1. Villages visited in the fieldwork, its geographic coordinates and the number of people interviewed

Village	Geographic Coordinates (X, Y)	Number of people interviewed
Boca da Barra	762935.64, 8830727.85	5
Ponta dos Mangues	765479.59, 8832323.99	11
Oitizeiro	768539.97, 8834633.41	10
Aracaré	770524.58, 8835375.34	10
Carapitanga	774240.62, 8837120.08	12

3. Results

3.1. Mangrove fishery resources and socio-economic importance

Different mangrove-fishery resources are exploited by the coastal communities of the São Francisco River Estuary. Fish are the most exploited resources, followed by crabs, mollusks and shrimps (Figure 2a). About 88% of the interviewees explore at least two different types of fishery resources, and 75% explore almost all mangrove-fishery resources of the mangrove environment. Therefore, they execute both activities of fishermen/fisherwomen and gathers of crabs and mollusks (Figure 3). Currently 90% of the

interviewees primarily depend on the mangrove fishery resources for their economic subsistence and 10% depended on the past.

Figure 2. (a) Exploitation and importance for income of the mangrove fishery resources. (b) Villages pointed out by the respondents as the most producers of fish and crab. (c) Percentage of respondents by class of mean weekly income generated by the sale of the mangrove fishery resources*. (d) Mangrove fishery resources indicated to have decreased yield. (e) Main reasons pointed out by the locals for the decrease in the fishery yield. (f) Alternatives pointed out by the respondents for local development and life quality improvement. (*exchange rate: 1USD equals to R\$ 2.576, in 3th December 2014).

Figure 3. (a) A fisherman fishing in the mangrove waters. (b) A crab gatherer catching the mangrove crab *Ucides cordatus*. (c) Two fishermen processing mollusks collected in the mangrove.

Fish are the most important source of income for the local populations (Figure 2a), and "Ponta dos Mangues" is the village showing the highest and remarkable fish production (Figure 2b). The interviewees pointed out about 12 types of fish caught in the waters of the mangroves (Table 2). Among them, *Mugil* sp. is the most harvest and indicated as the principal and more abundant fish in the mangroves (Table 2). *Centropomus* sp. is the second most exploited followed by *Diapterus rhombeus* and fish from the family Ariidae (Table 2). Less exploited fish are *Lutjanus synagris*, *Cynoscion leiarchus* and *Geophagus brasiliensis* (Table 2). Three types of fish cited by the local population as "tinga", "mirucáia" and "milombo", were not found in the literature and was not possible to be identified (Table 2).

These can represent fish with names that were strictly designated by the local population of the São Francisco River Estuary.

Table 2. Mangrove related fish used by the local populations of the São Francisco River Estuary and percentage (%) of respondents that use this type of resource.

Familly	Species or gender	Vernacular name given by respondents	% of respondents
Mugilidae (mullets)	<i>Mugil sp.</i>	"tainha"	100%
	<i>Mugil liza</i>	"curimã"	56%
Centropomidae (snooks)	<i>Centropomus sp.</i>	"robalo"	73%
	<i>Centropomus ensiferus</i>	"camurim"	10%
Gerridae (mojaras)	<i>Diapterus rhombeus</i>	"carapeba"	69%
Ariidae (catfish)	-	"bagre"	65%
Not identified	Not identified	"tinga"	40%
Lutjanidae (snappers)	<i>Lutjanus synagris</i>	"vermelha"	33%
Sciaenidae	<i>Cynoscion leiarchus</i>	"pescada"	29%
Not identified	Not identified	"mirucáia"	10%
Not identified	Not identified	"milombo"	10%
Cichlidae	<i>Geophagus brasiliensis</i>	"cará"	6%

From crustaceans, crabs are more exploited than shrimps (Figure 2a). Four different types of crabs were pointed out by the respondents (Table 3). Among them, the most exploited is *Ucides cordatus* which constitutes the second most important source of income for the local residents (Table 3, Figure 2a). The villages of Carapitanga, Oitizeiro and Aracaré are the highest producer of *U. cordatus*, where it constitutes the base of the local subsistence

economy (Figure 2b). Other economically important crab species are also exploited by the locals, but by less people (Table 3). Native shrimps that naturally occur associated to the mangrove environment (e.g. *Litopenaeus schimitti*, *Farfantepenaeus subtilis* e *Xiphopenaeus kroyeri*) are the least exploited resources, and are important source of income for only 4% of the interviewees (Figure 2a). The respondents pointed out that since the activity of aquaculture of the exotic shrimp species *Litopenaeus vannamei* have started in the study area, the fishery of native shrimps drastically reduced. From the mollusks, the mangrove oyster *Crassostrea rhizophorae* is the most exploited followed by *Mytella* sp., and the least harvest is *Anomalocardia brasiliensis* (Table 4). It is interest to observe that although these mollusks are highly exploited in the area, they are not considered as the most important for income generation (Figure 2a).

Table 3. Mangrove related crabs used by the local populations of the São Francisco River Estuary, and percentage (%) of respondents that use this type of resource.

Family	Species or gender	Vernacular name given by respondents	% of respondents
Ucididae	<i>Ucides cordatus</i>	"caranguejo"	88%
Portunidae	<i>Callinectes</i> spp.	"siri"	48%
Grapsidae	<i>Goniopsis cruentata</i>	"aratu"	35%
Gecarcinidae	<i>Cardisoma guanhumi</i>	"gaiamum"	31%

Most of the respondents (40%) sell the fish, crabs, shrimps and mollusks in the local market, although others (30%) sell for intermediate buyers. These intermediates buy the fishery products at low prices and sell it in other places, as in the capital city Aracaju, at higher prices. The average earnings obtained by the sale of the fishery per individual fisherman reaches less than 39 USD per week (Figure 3c), being not fixed and usually lower.

This value is lower when compared with the current weekly figure of the minimum Brazilian wage which correspond to about 71 USD (R\$ 181).

Table 4. Mangrove related shellfish used by the local populations of the São Francisco River Estuary, and percentage (%) of respondents that use this type of resource.

Familly	Species or gender	Vernacular name given by respondents	% of respondents
Ostreidae	<i>Crassostrea rhizophorae</i>	"ostra"	67%
Mytilidae	<i>Mytella</i> sp.	"sururu"	63%
Veneridae	<i>Anomalocardia brasiliiana</i>	"maçunin"	21%

3.2. Local perception on fishery shifts

Among the fishery products exploited by the local populations, the crab *Ucides cordatus* was, unanimously, the most indicated resource with decrease in yield during the last 13 years (Figure 3d). Fish in general was also highly indicated (Figure 3d). Most of the respondents pointed out the increase in the number of fisherman as the major cause for the reduction on fishery yield (Figure 3e). According to them, nowadays almost everybody in the villages is fisherman.

Shrimp farming was the second main reason indicated as the cause for the fishery decrease (Figure 3e), especially for the crab *Ucides cordatus*. Almost all interviewees said that the stock of *Ucides cordatus* drastically reduced (Figure 3d), with one period of about one year and a half, between 2000 to 2001, just after the beginning of the shrimp farming activities, when the crabs were found dead in their burrows. According to some respondents, the chemical products used in the shrimp farming were released in the mangrove waters killing the crabs. Moreover, they pointed out that for the installation of shrimp farming

enterprises many mangrove forests were deforested, reducing the areas for fishing and the crab stock. Less number of people indicated that the gather technique called "small-net" ("*redinha*") applied to catch the crab *Ucides cordatus*, as cause for the reduction of this crab fishery yield. (Figure 3d). In this technique the crab gather made a trap using nylon yarns from plastic bags and put it directly, or use branches of mangrove trees, in the burrow entrance of the crabs. The respondents pointed out that the "small-net" catch the females and the small crabs, reducing the crab stock.

The third reason most indicated for the fishery fall was the decrease of the river floods, caused by the built of dams upstream the study area (Figure 3d). According to the local people, the river floods did not occur after the functioning of the Xingó dam, the closest to the study area. They said that when there were the floods, they used to catch fish and shrimps in abundance, and after the dam the fish yield reduced. They attribute this to the lack of water because the dams hold it, and thus, the fish cannot come because there is not enough water.

3.3. Population opinion for the local development and life quality improvement

When asked about the possibilities for the local development and life quality improvement all respondents pointed out that the introduction of a small-scale industry to process the fishery resources will be the best alternative (Figure 2f). They stated that this industry will be an alternative of job for them for which they will sell the fishery products. The second and third most indicated alternatives were the support of government to cultivate native oysters and fish, which will be an alternative of income and to buy motorized boats which will allow them to explore other mangroves area far from the villages (Figure 2f).

Creation of a conservation unit of sustainable use and tourism were the fourth and fifth alternatives indicated (Figure 2f). Although most locals (81%) agreed with the first alternative, and stated that it is possible a combination of the mangrove resource exploitation

and areas of conservation, few (19%) point out that it is not possible to conserve the mangroves, because they do not have another source of income to survive unless to explore these resources. Remarkably, the introduction of more shrimp farming is not seemed as a good alternative for local development. Only few people indicate this activity as important, stating that it will be source of job for them (Figure 2f).

4. Discussion

4.1. Mangrove fishery resources and socio-economic importance

The results presented here show how the economic subsistence and life of the coastal communities of the São Francisco River Estuary rely on the mangrove environment and fishery resources. Mangrove ecosystems feature a high biomass and biodiversity concentration characterized by abundance of fish, crustaceans and mollusks, which constitutes fisheries of major value of marketed natural resources, supporting the exploitation by many traditional populations that survive on it (Hamilton et al., 1989; Rönnbäck, 1999, Walters et al., 2008, Souto, 2008b). In this study we recorded a high exploitation of this diversity, wherein all mangrove fishery resources are exploited by the local populations. Fish was the most diverse and exploited group probably due to it higher market value than the other resources, especially for snooks (*Centropomus* sp.), and due to their high abundance, particularly for mullets which is the most conspicuous fish group in mangroves (Christesen, 1983). Lacerda (2002) have reported that these two groups are the most commercial important in the Brazilian mangroves. Additionally, all the fish species exploited by the coastal populations of the São Francisco River Estuary are among fish families that utilize mangroves as habitat and are of economic importance (e.g. Rönnbäck, 1999). Majority of the fish groups (e.g. mullets, snooks, mojaras, catfish, snappers) was also recognized as fish

from mangroves by the local population of Acupe (Bahia), also in the Brazilian Northeast (e.g. Souto, 2008a).

The species of crabs exploited by the locals of the São Francisco River Estuary are among the most important crustacean captured and commercialized in Brazil (e.g. Alves and Nishida, 2002; 2003, Nishida et al. 2004; Alves et al. 2005, Souto 2007; Firmo et al., 2012). Nevertheless, it is remarkably the highest exploitation and the economic importance of the crab *Ucides cordatus*. One of the facts that can contribute for this, is that the mangrove crab constitutes a typical dish in the cuisine of Brazil Northeast, specially, in Sergipe State, where it is considered an identity of the local gastronomy. Similarly, other studies also have documented the importance of *U. cordatus* as fishing resource and source of income and employment for the communities residing in the vicinity of Brazilian estuaries (e.g. Nodi, 1994; Ivo and Gesteira 1999; Rodrigues et al. 2000; Glaser, 2003; Alves and Nishida 2002; 2003; Souto, 2007; 2008a). Thus, this crab species has a significant socioeconomic importance and significant poverty alleviation function in the coast of Brazil, particularly, in the North and Northeast (Glaser and Grasso, 1998; Alves and Nishida 2003; 2004; Glaser, 2003).

Mangrove estuarine areas often support an abundance of mollusk species that are largely sessile in nature and constitute an important *in-situ* fishery (Macnae, 1974; Macintosh, 1982; Matthes and Kapetsky, 1988; Nishida et al., 2006b). The three species of mollusks collected in the mangroves of the study area are among the most prominent in artisanal fishery of Brazilian mangroves (e.g. Schaeffer-Novelli, 1989, Souto, 2008a; Souto and Martins, 2009; Nishida et al., 2006a). Although these mollusks are the third most exploited resource in the study area, due to their low market value in the region they were not account as major importance for income generation.

Shrimp farming of the exotic species *Litopenaeus vannamei* has a negative impact on the artisanal fishery of native shrimps that occur in mangrove waters. Due to competition with this activity that starts in ends of the 90's (Santos et al., 2014), local fishermen stop the exploitation of native fish shrimps, and nowadays few locals develop this fishery. This activity when carried out without adequate management, as occur in the study area (e.g. Santos et al., 2014) can cause socioeconomic impacts as loss of fisheries livelihoods (Primavera, 2006).

4.1. Local perception on fishery shifts

Local people generally will observe changes in the ecosystem where they live if this results in an increase or decrease production of resources (Ward et al., 2000, Satyanarayana et al., 2013). In the study area, due to a high relationship and economic dependence on mangrove fishery resources, changes undergone in fishery yield and causes for it were wildly perceived by the local populations. The main cause for decrease in fishery yield was the high number of fisherman exploring the mangrove resources. This reflect the lack of jobs and alternative income in the study area, a social problem not only for the local subsistence but also for the sustainable use of the mangrove resources.

It is interest to note that there is a consensus about a high decrease in the yield of the crab *Ucides cordatus*, wherein shrimp farming was indicated as one of the major causes. The information given by the locals about the high mortality of this crab due to the release of chemical products used in shrimp farming are reinforced by the founds of Carvalho (2004) who reported that the effluents from this activity are released directly into the estuary. The pollution of coastal ecosystems greatly affects human communities along the shore which are used to living in harmony with these environments (Diegues, 1999), and local people are in overall concerned that water pollution can cause massive fish mortality (e.g. Satyanarayana et

al., 2013). Still in regard to decrease in the yield of the crab *Ucides cordatus*, the "small net" which was pointed out as the minor factor, is legally prohibited by the IBAMA (IBAMA 2003a, 2003b) because it is less selective in the crab capture (Cortês et al. 2014), in agreement with the perceptions of some fishermen.

Finally, the least cause indicate to overall fishery yield reduction was the decrease of the river floods, caused by the built of dams upstream the study area. Corroborating with the information of the locals, studies have shown that the river flow, suspended and organic matter as well as nutrients have reduced after the Xingó dam (e.g. Knoppers et al., 2006, Medeiros et al. 2007), which may impacted the fish communities and contributed to the fishery decrease. Moreover, studies in have reported that the regularization of the river flow, caused by dams, can affect fish migration and breeding (e.g. Dahdouh-Guebas et al., 2010).

4.3. Considerations for local management and conservation

Since 2004 the São Francisco River Estuary is part of a State Protected Area of sustainable use, the "APA litoral norte", whose objectives include: the promotion of the socio-economic and sustainable development by activities that protect and conserve the ecosystems or essential processes to the biodiversity, the maintenance of ecological attributes, and the improvement of the life quality of the local populations (Sergipe, 2004). This highlight the need to consider the local opinion as subsidies for the establishment of social programs to achieve these objects.

The alternatives such as: introduction of a small-scale fishery processing industry, government support to cultivate native oysters and fish and to buy motorized boats, tourism and the creation of a conservation unit of sustainable use, were all highly accepted by the locals and was seemed to be ways to reduce the fishery pressure on the mangrove resources and alternatives of job and income and for their life quality improvement. Consequently, these

are good socio-ecological alternatives for poverty alleviation and should be considered for the local sustainability. On the other hand, the introduction of more shrimp farming was not seemed as a good alternative by the locals, which have argued that this activity employs few numbers of people, two or three persons by enterprise, and only benefits the proprietor who is always from another place.

The small-scale fishery processing industry besides be an new alternative of jobs, it is also important to break the dependence of the fishermen on intermediate buyers, which put the local population in an extreme disadvantage, with low profit and dependence on the intermediates buyers. A similar situation was also found by Alves et al. (2005), in the coastal communities of the Mamanguape River, (Paraíba State, Northeast Brazil), where the crab gatherers economically depended on buyers, who are therefore in a position to explore them.

In regard to government support to cultivate native oysters and fish, the study area shows potential for this, especially in mangrove-friendly aquaculture practices (Santos et; al., 2014) of the mangrove oyster *Crassostrea* sp. (e.g. Moura and Meira, 2002) and native fish species traditionally cultivated (e.g. Santos, 1997). Mangrove-friendly aquaculture is developed in the mangrove waters without deforestation and is a socio-sustainable practice (Primavera, 2006). Additionally to this, the government support to buy motorized boats will allow the locals to explore other mangrove areas far from the villages, and, therefore reducing the fishery pressure on one single area, as well as offering to the locals better working conditions, because in the currently situation, the fishermen reach the mangrove areas by canoe, mainly without motor, or by foot. This is the also reality of other small-fishery in mangroves areas (e.g. Fiscarelli and Pinheiro, 2002).

Although the study area is part of a large conservation unit of the category environmental protected area (APA), we identified that the socio-local characteristics of the study area wherein local populations rely on mangrove fishery exploitation, best fit this area

in a conservation unity of the category "Sustainable Development Reserve". This category is a natural area that houses traditional populations, whose existence is based on exploitation of natural resources, and has the basic objective of preserving nature and at the same time ensuring the conditions and means necessary for improvement of the local life quality and exploitation of natural resources (Brasil, 2000).

Developing sustainable management policies that also consider the subsistence requirements of local people, is a high priority (Dahdouh-Guebas et al., 2006). For this, the integration of indigenous knowledge into contemporary frameworks for conservation and sustainable management of natural resources is become increasingly important in policies on an international and national level (Dahdouh-Guebas and Rist, 2006).

4. Conclusions

The present study documents that mangrove fisheries is the main economic subsistence base of the coastal communities on the São Francisco River Estuary. We also showed that the local populations have a substantial local knowledge about the changes and impacts on the stocks of the fishery resources, and that the information given by them are in overall in accordance with the scientific literature.

The information recorded in this study can serve as a base for the local management. For example, activities pointed out by the locals to improve their livelihood such as: creation of a small-scale fishery processing industry, government support to cultivate oysters and fish and ecotourism are good alternatives for poverty alleviation and should be considered for the local sustainability. Considering the high importance of mangrove fisheries for the local populations, we strongly recommend the implementation of policies and strategies that includes the sustainable resource utilization of the mangroves fisheries, instead of the complete ban of the ecosystem resources, the maintenance and improvement of the life

quality of the local population by the fishery rational use and implementation of new income alternatives.

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CAPÍTULO 3

**Local knowledge and capture practices of the most
exploited mangrove crab *Ucides cordatus* in the São
Francisco River Estuary (Northeastern Brazil)**

CAPÍTULO 3

Local knowledge and capture practices of the most exploited mangrove crab *Ucides cordatus* in the São Francisco River Estuary (Northeastern Brazil)

Abstract

The mangrove crab *Ucides cordatus* is one of the most exploited fishery resources in the Brazilian mangroves and has a particular socio-economic importance. The São Francisco River Estuary (Northeastern Brazil) comprises a significant mangrove area used by local populations whose subsistence depends on fishery, on *U. cordatus* in particular. This study analyzed the biological, ecological and conservation knowledge on the mangrove crab *U. cordatus* and the practices of capture applied by the local populations of this estuary. Five villages were sampled in January 2013 and 48 inhabitants were interviewed using structured interviews which were digitally recorded, transcribed, and analysed qualitatively and quantitatively. Most of the locals catch the crabs by "arm" (the fisherman insert his arm in the crab burrow, 17%), "plugged" (the fisherman close the crab burrow using the mangrove mud, 27%) or a combination of both (31%), which are allowed by IBAMA (Brazilian Institute of Environment and Renewable Natural Resources). The practice of "small net" (the fisherman makes a small net of nylon yarns and put it on the crab burrow) is not allowed, but used by 14% of the respondents who showed conservation knowledge, selecting burrows of large male crabs. Three remarkable periods about the crab's life cycle were pointed out by the locals, information which can assist in defining the period of close seasons. The crab gatherers also indicated the mangrove areas important for the conservation of the crab stock. We concluded that the local populations have a substantial knowledge about *Ucides cordatus* population and body sizes, habitat, life cycle and sex ratio that can aid the formation of management and conservation plans for socio-ecological sustainable fisheries.

Keywords: traditional knowledge, ethnoecology, mangrove crab, fishery, crustaceans.

1. Introduction

Mangroves are coastal ecosystems that occur in the tropical and subtropical zones where they fulfill several valuable environmental, ecological, social and economic services (Alongi, 2002; FAO, 2007). Among these services, mangroves sustain a variety of aquatic and (semi)terrestrial fauna which are exploited by local and deprived human communities in small-scale fisheries (Rönnbäck, 1999, Walters et al., 2008, Satyanarayana et al., 2013; Santos et al., 2014a). These human communities have an intrinsic relationship with mangroves, wherein a specific way of life in which economic, social and cultural activities fundamentally depends on the ecosystem resources (Diegues, 1999), therefore, generating substantial local ecological knowledge and management practices in the exploitation of them (e.g. Alves et al., 2005, Nishida et al., 2006; Souto, 2007, 2008; Souto and Martins, 2009; Ferreira et al., 2009; Firmo et al., 2011, 2012; Magalhães et al., 2012; Cortês et al., 2014).

Local ecological knowledge (LEK) is defined as the knowledge and experience of traditional communities regarding the natural and supernatural worlds that are transmitted orally from one generation to another (Berkes, 1993; Castro, 2000, Cortês et al., 2014). The knowledge derived from traditional fishermen may contribute to strategic ecological managements (Seixas and Begossi, 2001), particularly in research areas with scarce or non-existent data (Ruddle, 1994; Johannes, 1998; Alves et al., 2005). Considering this, socio-ecological studies, based on LEK are becoming more and more used to approach mangroves resources and management (Dahdouh-Guebas, et al. 2006).

In Brazil, the country that has the third largest mangrove area in the world (Magris and Barreto, 2010; Giri et al., 2011), local populations have been extensively exploiting mangrove resources, specially *Ucides cordatus* (Linnaeus, 1763), a semiterrestrial crab that lives only in mangroves and a keystone species of this ecosystem (Melo, 1996, Schories et al. 2003). This

crab holds a major socio-economic importance, particularly in the northern and northeastern Brazilian coast, constituting one of the main source of income for many human populations who show a high local ecological knowledge on the species (e.g. Fiscarelli and Pinheiro, 2002; Glaser, 2003; Glaser and Diele 2004, Alves and Nishida, 2003; Alves et al. 2005; Passos and Di Benedetto 2005, Souto, 2007; Firmo et al. 2011, Magalhães et al., 2012; Santos et al., 2013; Cortês et al., 2014).

Despite its socio-ecological importance, declines of *U. cordatus* have been reported in many coastal regions of Brazil and were related to mangrove habitat destruction, overfishing and diseases, as the Lethargic Crab Disease (LCD) which caused massive mortalities of *U. cordatus* (Maneschy 1993; Boeger et al. 2005, Diele et al., 2005). Decreases in this crustacean populations have created social problems in the communities surroundings mangrove areas and seriously affected the economic welfare of the poor people who depended upon crab harvesting for their livelihood (Firmo et al., 2011).

The São Francisco River Estuary (State of Sergipe, Northeastern Brazil) has a high mangrove extent in which various fishery resources are exploited by local populations, and *U. cordatus* is the second most economic-important (Santos et al., 2013). Despite this socio-biodiversity, there are few ethnoecological studies related to mangrove fisheries in this region (e.g. Cunha and Holanda, 2006; Santos, 1997) and particularly in regard to *Ucides cordatus*, this is the first report in this estuary. This study analyzed the biological, ecological and conservation knowledge on the mangrove crab *U. cordatus* and the practices of capture applied by the local populations of this estuary and considered how this knowledge can aid the formulation of conservation and management plans for the socio-ecological sustainability of the crab fishery.

2. Material and Methods

2.1. Study area

The São Francisco River is one of the most important Brazilian water resources and is considered the River of National Integration, draining seven states along its 2,863 km. The river basin (636,919 km²) is divided in four sub-regions from its nascent to its estuary: high, medium, sub-medium and low São Francisco (ANA, 2005). The estuary of this river is located in the low sub-region, on the boundary of Sergipe and Alagoas States (10° 30' 27"S, 36° 23'45"W) (Figure 1a, 1b), in the Northeast of Brazil.

The study area corresponds to the southern part of the São Francisco River Estuary, on the State of Sergipe (Figure 1c), covers approximately 192.35 km², is part of the municipalities of "Brejo Grande" and "Pacatuba", and is included in a State Environmental Protected Area (APA "Litoral Norte"), a Conservation Unit of sustainable use (Sergipe, 2004). About 93% of the study area is occupied by natural cover, showing a high extent of mangroves (30.1 km²) which are distributed parallel to the coastline and along tidal canals that part from the São Francisco River mouth (Figure 1c). Land use to human activities (3.6 km²) are aquaculture and agriculture (Santos et al., 2014a). The local inhabitants are distributed along eight small villages located parallel to the mangrove forests (Figure 1c) and they are deprived population composed of native residents showing low human development indices (0.584 and 0.550). The mangrove fisheries constitute the main base of the local subsistence economy, specially the mangrove crab *Ucides cordatus* which is the main resource exploited in the villages of Oitizeiro, Aracaré and Carapitanga (Santos et al., 2013, Figure 1c).

Figure 1. (a) Map of South America and Brazil indicating the location of the São Francisco River basin (adapted from ANA, 2005). (b) The São Francisco River basin with its four divisions (adapted from ANA, 2005). (c) Map of land use and cover of the São Francisco River Estuary, the study area.

2.2. Data collection and analysis

On January 2013 fieldworks were carried out in the São Francisco River Estuary to collect data about local knowledge on biological, ecological and conservation aspects of the mangrove crab *Ucides cordatus* and the practices of capture applied by the local populations of this estuary. By a set of eight coastal villages, we sampled five villages (Table 1, Figure 1c) which were chosen because they are the most important in terms of crab production in the region. The geographic coordinates of each village visited were recorded in a GPS (Global Positioning System, Garmin eTrex Venture HC). A native inhabitant acted as local mediator (e.g. Albuquerque et al., 2010a) who conducted us to the villages and introduced the people to be interviewed. Only local specialists (e.g. Albuquerque et al., 2010a), i.e., people that fish or used to fish the mangrove crab were interviewed. Besides the aid of the local mediator, the

snowball technique (Goodman, 1961) was also applied, in which the respondent indicates another one and so on.

We applied structured interviews (e.g. Alexiades, 1996; Albuquerque et al., 2010b) which were digitally recorded, filmed and photographed, when the interviewees allowed. The interviews were individual and collective in focal groups with number varying from two to six people. The interviews contained open-ended, yes/no and multiple choice questions. The questions were about biological and ecological aspects of *Ucides cordatus* as life cycle, spatial distribution, temporal abundance, and about the gathering techniques applied by the local populations to fish this species and their conservation knowledge. A total of 48 inhabitant were interviewed (16% of the local human population), with the participation of 35 men (73%) and 13 women (27%) whose ages ranged between 18 and 73. A presentation of the fieldwork group and the aims of the research were explained before starting each interview and the permission to record, film and photograph were ask for all participants. We were precluded from adopting a formal approach using interview consent forms, due to the poor level of organization of the communities and high illiteracy rates (e.g. Alves and Nishida, 2002, 2003; Alves et al., 2005, Firmo et al., 2011).

Additionally, on February 2013, a tour guide (e.g. Albuquerque et al., 2010b) was carried out in the mangrove forests of the estuary in order to develop the *in situ* register, by digital filming and photographs, of the catch of *U. cordatus*, i.e., the visual ethnographic (e.g. Souto, 2008; 2010). The tour guide was made by one native inhabitant who is a long-term crab gatherer and conducted the fieldwork group to the mangrove areas that he use to catch de crab *U. cordatus*.

2.3 Analysis of data

All digitally recorded interviews were transcribed. The data were analyzed qualitatively, using the union model (Marques et al., 1991), in which all information collected on the interviews were considered. After that, the responses were categorized and tabulated in Excel spreadsheets, in terms of number of people which gave each type of response, and its percentage in relation to the total of interviewees, and thus analysed quantitatively, and graphs were produced. The information provided by the participants was compared with those from the specialized academic literature, following ethnoscientific notions with a balance between emic and etic focused approaches (Sturtevant, 1964; Magalhães et al., 2012).

For the visual ethnography of the fishery of *Ucides cordatus*, all filming were edited in the software Pinnacle Studio Plus, in order to select photographs that sequentially describe and illustrate the processes of the catch of the mangrove crab. Moreover, photographs taken by camera were considered in the composition of the visual ethnography.

Table 1. Villages visited in the fieldwork, its geographic coordinates and the number of people interviewed

Village	Geographic Coordinates (X, Y)	Number of people interviewed
Boca da Barra	762935.64, 8830727.85	5
Ponta dos Mangues	765479.59, 8832323.99	11
Oitizeiro	768539.97, 8834633.41	10
Aracaré	770524.58, 8835375.34	10
Carapitanga	774240.62, 8837120.08	12

3. Results and discussion

3.1. Local knowledge on the mangrove crab *Ucides cordatus*

The fishery of the crab *U. cordatus* is an activity that starts early in the life or the coastal populations of the São Francisco River Estuary. Almost half of the interviewees began to catch this crab when they were children with less than 10 years old. Another part started younger, and fewer began from 21 years old (Figure 2a). Both genders are involved in the fishery of the mangrove crab. The local people learned to catch *Ucides cordatus* with their parents, brothers and sisters, thus this activity is orally passed throughout the generations. This early contact with the mangrove and the crab fishery, since they were children or young, allowed them to develop a high knowledge about ecological and biological aspects of *Ucides cordatus*.

The local populations call the *Ucides cordatus* as "crab" and according to them this crab occurs more in the mangroves where is most found the plant species *Rhizophora mangle*, locally called "tough mangrove" ("*mangue brabo*"):

"All areas with more crab is the tough mangrove".

In accordance with this, Piou et al. (2009), found that *R. mangle*-dominated areas is the preferred habitat of *Ucides cordatus*. The mangrove forests dominated by this plant species is also the areas that the fishermen preferably use to catch the crab, because, according to them, the roots of this species are soft and do not hurt their feet. On the other hand, they said that nobody use the mangrove areas dominated by the species *Laguncularia racemosa* because it has hard roots which hurts their feet.

When asked about the spatial distribution of large and small crabs in the mangrove vegetation, the responses given by the locals were divergent (Figure 2b). Most of the respondents reported that large and small crabs occur together in the same mangrove forest (Figure 2b). Another part said that large crabs occur in the mangroves with high density of

rhizophores, the prop roots of the *Rhizophora mangle*, which are locally called “gaiteiras” (Figure 2b). This type of mangrove is called by them as a “fenced mangrove”. In turn, the small crabs occur in the margin of the mangroves or where the vegetation is not dense, which they call as a “thin mangrove” (Figure 2b). Corroborating with these answers, in our posterior study carried out in the mangroves of the study area (Santos et al., 2014b), we found that large and small crabs can occur in the same area of a mangrove, but large crabs are more frequently in areas dominated by *Rhizophora mangle*, and the smaller in areas with the occurrence of *Laguncularia racemosa*. Additionally, Piou et al. (2009), in a study taken place in the North of Brazil reported that, in general, big crabs dominate the areas with *Rhizophora mangle*, corroborating with part of the information gave by the fishermen.

The local populations showed a detailed and convergent knowledge about the life cycle of *Ucides cordatus*. According to them, the crab life cycle is characterized by three remarkable periods popularly called: “walking”, “fattening” and “peeling” (Figure 2c). The “walking” corresponds to the reproductive period. The fishermen reported that in this period the crabs leave their burrows and walk as “crazy” on the mangrove substrate for mating, wherein the males fight among them and the females look for a male. This information is consistent with the scientific literature (e.g. Pinheiro and Fiscarelli, 2001; Diele and Koch, 2010; Linhares and Silva, 2012). Most of the respondents pointed out that the “walking” occurs in the months of January and February (Figure 2c), while less fisherman (15%) showed a more detailed knowledge, making reference for the occurrence of three periods of the “walking” during these months. Corroborating with this, Souto (2007), in a study carried out in mangroves on the Brazilian Northeast, also recorded that local fishermen discriminated three periods of “walking”. Additionally, other ethnological studies have reported that the mangrove crab “walking” occurs in the months of January and February (e.g. Magalhães et al., 2012; Cortês, 2014). Two fishermen related that during the “walking” the male crabs

secrete a foam from their mouth. This was also observed in the scientific literature (e.g. Linhares and Silva, 2012; Nascimento 1993a; Pinheiro and Fiscarelli, 2001) and by other Brazilian local populations (e.g. Souto, 2007). Linhares and Silva (2012) have hypothesized that this foam may contains a pheromone that facilitates the approach of the males and females.

The "fattening" is pointed out by the communities as the period in which the crabs "disappear" of the mangroves, staying deep in their burrows feeding on the mangroves leaves that fall, and thus, they are more difficult to found and catch. The respondents do not recognize the "fat crab" by a morphological feature, thus, it is recognize by the crab behavior of "disappearing" from the mangroves and by the period of the year when it occurs, which they called "month of São João", corresponding to May and June (Figure 2c). This period coincides with the winter season, which is rainy and according to the fishermen, there are a high fall of mangrove leaves which are used as feed by the crabs. This information is consistent with other reports (e.g. Pinheiro and Fiscarelli, 2001; Alves and Nishida, 2002; Fiscarelli and Pinheiro, 2002; Nunes, 2004; Wunderlich et al., 2008 Cortês et al., 2014), which indicated that *U. cordatus* crabs stock their burrows with leaves and seal the entrance with mud in order to be well-fed in the period preceding ecdysis.

The "molt", also popularly called the period of "milk crab" or "peeling", corresponds to the crab ecdysis. The crabs are popularly called "milk crabs" due to their milky-white color caused by the accumulation of carbonates in their hemolymph, used to hardening the carapace (Pinheiro and Fiscarelli, 2001). According to the local people in this period the crab is peeling and soft, changing their carapace, which is popularly called "hull". The fishermen pointed out that in the "peeling" the crabs go to intertidal flats, locally called "*apicum*", where they stay and built new burrows, in order to dry and harden the carapace:

"The crab only comes to the "apicum" in his time of peeling. October, November he's peeling, that's when he comes to the "apicum" to sunbathe, he peels and the hull heats and hardens again, it is the period that he also grows, when he peels."

Figure 2. (a) Age group that the fishermen start to fish the crab. (b) Spatial distribution of the crabs, according to the fisherman. (c) Periods of the crab life cycle in the view of the locals. (d) Abundance of the crabs in the mangroves, according to the fisherman. (e) Fish methods applied to gather the crab. (f) Mangrove areas for the crab conservation, in the view of the locals.

In the view of the fishermen the "*apicum*" is an area not frequently inundated, with sandy sediments where *U. cordatus* can have enough sunbath to harden its carapace. After the molting, when the new hard carapace has been formed, and the crab grew, it came back to the mangrove mud. According to the scientific literature intertidal flats ("*apicum*") corresponds to a mangrove zone located above the high-tide line with soil generally sandy, sunny, lacking vegetation or with only sparse, low growth (Nascimento, 1993b, Schaeffer-Novelli, 2000), which agreed with the information given by the fishermen. Studies have reported that the crab grows in the molting and burrows into the mangrove substrate and undergo carapace change (e.g. Nordi, 1994; Magalhães et al., 2012) and the that recruitment of *U. cordatus* occurs at the boundary of "*apicum*" and mangrove forest (Schmidt et al., 2013). Only one ethnoecological study have recorded fishermen indicating that the crabs usually undergo the molting in more elevated and dry areas (e.g. Alves and Nishida, 2002), corroborating, in part, with the information given by the locals of the study area. Nevertheless, the information that the crab moves the "*apicum*" in order to sunbath to harder their carapace during the molt has not been before described in the scientific literature and in others ethnoecological studies.

Most of the respondents pointed out that the "molt" occurs on September and October (Figure 2c), as recorded by other authors (e.g. Souto, 2007; Magalhães et al., 2012). The respondents indicated that they do not catch the crab in this period, because it is not appropriate for consuming, thus they stop the catch during approximately 2 months, when they only exploit other mangrove resources.

The communities pointed out that there are differences in the abundance of *Ucides cordatus* along the year, which are linked with the periods of the crab life cycle and the season (Figure 2d). Majority indicated that there is high abundance of *Ucides cordatus* during the "walking", and others that there is a decrease in its abundance during the "fattening" (Figure 2d). This can be related to the different behaviors of *Ucides cordatus* in these periods

and how the locals perceive it. For instance, in the "walking" the crabs leave their burrows, thus they are more visible for the fisherman. In contrast, in the "fattening" they are deep on the burrow and difficult to catch, thus less visible for the fisherman. Few people indicated that the abundance does not change along the year (Figure 2d).

According to Souto (2007), a detailed and precise perceptions of the crab life cycle aspects by fishermen, as observed in the present study, is related to a close relationship between the emic knowledge and the optimizing the production of the crab fishery. Since the study area lacks of employments and income alternatives, the local economic subsistence is primarily based on the crab fishery, thus requiring a substantial knowledge about the crab.

3.2. Gathering techniques to catch *Ucides cordatus*

In the São Francisco River Estuary, the local populations apply three main techniques to gather the mangrove crab, called: "arm" (*braceado*), "plugged" (*tapado*) and "small net" (*redinha*). Most of the fishermen use both techniques of "arm" and "plugged" (Figure 2e), which are the most traditional in the study area and allowed by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA).

In the "arm", firstly the crab gather looks for a burrow (Figure 3a), and when found, he removes some roots of *R. mangle* (Figure 3b), which may block him to introduce the arm in the crab burrow. He first dig the mud in the burrow in order to found and see the position of the crab (Figures 3c, 3d). After that, once the crab is found, he seizes the crab from the dorsal carapace and pull it up (Figure 3e, 3f). There were burrows that the gather cannot found the crab, because it was very deep, thus he/she left this burrow and looked for another one.

Figure 3. Capture of the mangrove crab by the technique of "arm".

In the "plugged", firstly the crab gathers introduce their arm in the crab burrow in order to see the direction of it and remove the water. After that, the fishermen plug the crab burrow with the mangrove mud using their feet. Then, they wait for about 15 minutes which is the period that the crab came for the surface, but it stay locked because the burrow is plugged, and the gather catch it near to the burrow entrance. Thus, in this technique it is not necessary to put the arm deep in the burrow as in the technique of "arm". Most of the gathers instead of waiting 15 minutes, they continue to "plug" other burrows, and then return for the first burrow that they plugged to catch the crabs. According to the interviewees, the crab came

for the burrow surface in order to breath, this same information was also recorded by Souto (2008) in other Brazilian fishery community.

The informants reported that it is faster to catch by "arm" than by "plugged". Nevertheless, they apply both techniques, because when the conditions are not favorable to catch by "arm", for example when the burrow is very deep, they use the "plugged". Therefore, few people use exclusively one of these two techniques (Figure 2e). "Arm" is a common method widely used throughout Brazilian mangrove forests (e.g., Souto, 2007, 2008; Nordi et al., 2009, Magalhães et al., 2011; Cortês, 2014), while the "plugged" has been described mainly for the Northeast coast (e.g. Souto, 2007, 2008; Nordi et al., 2009; Magalhães et al., 2011; Nascimento et al., 2012).

"Small net" is the third technique applied, but by few people (Figure 2e), although some interviewees said that almost everybody in the communities use it. This can indicate that because this method is legally prohibited (e.g. IBAMA, 2003a), the interviews were apprehensive in saying that use this. In this technique the crab gather made a trap using nylon yarns from plastic bags and put it directly in the burrow entrance of the crabs (Figure 4a) or may use branches of trees removed from the mangrove to put it in the entrance of the burrows. Within one to two hours they came back to the first burrow they put the trap, to catch and "clean" the crabs, i.e., to remove the "small net" from them. The figure 4b shows a crab caught in the "small net". The local perceptions about the use of the "small net" are divergent, with part of the locals (14%) indicating it as the best and easiest way to catch the mangrove crab, because they do not get dirty with the mangrove mud as in the "arm" and also they do not cut or injure their feet as occur in the "plugged". On the other hand, other interviewees (31%) consider this a wrong practice, because it catch female and the small crabs.

The "small net" is legally prohibited by the IBAMA (IBAMA 2003a, 2003b). The impacts of this technique are basically three: pollution from nylon threads which are sometimes abandoned in the mangroves, less selective capture and cutting of the roots of *Rhizophora mangle* to fix the trap (Nascimento et al., 2012, Cortês et al. 2014). Although this practice is considered predatory and is legally prohibited, it is still widely used (Nascimento et al., 2012).

According to the gathers that use the "small net" in the study area, they now the correct burrows to put the trap, selecting the burrows of big and male crabs, and when small and female are caught, they "clean" the crabs and leave them in the mangrove. They can identify the size of the crabs by their track and the size of burrows, and differentiate the sex based on the tracks left on the burrow entrance. According to them, the tracks and burrows of small crabs are also small, while the larger crabs have big burrows and larger tracks.

During the guide tour, the crab gathering showed the difference between the tracks of males and males. According to him, the tracks left in the mud by the male is spread (Figure 3d) while the female's track is narrower and aggregated (Figure 3c). This difference between male and female tracks is related to the absence of bristles on the female pereopods (Pinheiro and Fiscarelli, 2001; Cortês et al., 2014) . Similar reports of sexual differentiation using indirectly characteristics of the crab's burrow and track were also found by others studies, for *Ucides cordatus*, and also for other crab species habiting the mangrove (e.g. Maneschy, 1993; Fiscarelli and Pinheiro, 2002; Alves et al., 2005; Souto, 2007, 2008; Firmo et al. 2011, 2012., Cortês, 2014).

Figure 4. (a) "Small-net" on the entrance of the mangrove crab *Ucides cordatus* burrow. (b) a mangrove crab captured by the "small-net" trap. (c) Tracks of the female *Ucides cordatus*. (d) Tracks of the male *Ucides cordatus*.

3.3. Contributions of local knowledge for conservation and socio-sustainability of *Ucides cordatus* fishery in the São Francisco River mangroves

The connection between fishermen and crabs has important implications for conservation because it is closely related to the intensity of capture (Souto, 2007). The knowledge and practices applied by the local populations of the São Francisco River Estuary demonstrate that they have a high comprehension of biological and ecological aspects of the crab *Ucides cordatus* with important contributions for the conservation of the species. Among the aspects analyzed, the locals showed a detailed and convergent knowledge about the crab life cycle. This information can assist state environmental agencies in defining the period of close seasons, when the capture of the crab is prohibited because the species is in reproductive stages, as in the "walking", or during the crab ecdysis. All of the interviewees said that they

not catch the crabs for sale during these periods, and 63% of them recognize the importance of the close seasons for the maintenance of the species. Another important information given by these populations is that *Ucides cordatus* moves to the "apicum" during the ecdysis. This new information reinforces that for the biological cycle of the *U. cordatus*, it is extremely important to conserve the "apicum", a mangrove vegetation physiognomy that has been very threatened, specially by shrimp farming.

When asked about which are the important mangrove areas for the conservation of the crab *U. cordatus*, majority of the fishermen pointed out that it is important to conserve all mangrove areas. Nevertheless, others indicated that it is not possible to conserve the mangroves or the crab, because they do not have another source of income to survive (Figure 2 f). This shows the need for other income alternatives in the study area, as pointed by Santos et al. (2013). Additionally, it is important to highlight that the locals have the comprehension that it is important to stop the harvesting, in order to allow the recovery of the crab stock:

"If there were works for everyone, to leave the mangrove to produce more crab, you know... Work for everybody in the community, in this way, we could improve. But so, who is going to want to starve? We have to work in the mangroves."

Among the mangrove areas, the most indicated by the locals for the crab conservation was those associated to the village of Carapitanga (Figure 2f). In these mangroves there are the presence of some forests with the largest structural development showing trees of *R. mangle* reaching heights up to 20 m (Santos et al., 2014a). This information can assist scientists and environmental agencies to delineate mangrove areas for the crab conservation.

The local populations showed a high ability to differentiate male, females and size of the crabs by indirect evidence as burrow size and tracks. According to Cortês et al., (2014) this discrimination allows the gathering of specimens with the greatest commercial value and contributes to resource conservation because females are spared and stock replacement is

maintained. This knowledge seems to be endemic in traditional coastal communities throughout Brazil (Alves et al., 2005). If this behavior were recognized and encouraged, the fishermen would become partners to state and federal agencies in public conservation policies (Firmo et al., 2011).

Additionally, the locals showed gathering practices that have a positive impact in the maintenance of the crab stock. Most of them use traditional techniques, as "arm" and "plugged", which are allowed by the IBAMA. Those fisherman that use the prohibited technique of "small net" also demonstrate conservation knowledge, once they recognize and select the burrows of big male crabs. This knowledge reduce the impact of this gear on the crab population (Cortês et al., 2014). Although this technique is seemed to cause impacts in the mangrove (e.g. Nascimento et al., 2012; Cortês et al., 2014), it is important to consider that its use does not increase the number of crabs gathered, but it is safer and preserves the physical health of the gatherers, which is important for those with long-term economic dependence on this activity (Cortês et al., 2014). Therefore, considering these aspects of the "small net", and the conservation knowledge applied by the communities when using this technique, the normative of the IBAMA that prohibits it should be re-examined in order to achieve an equilibrium between a rational exploitation of the crab and the social, physical and health welfare of fishermen communities.

Brazilian governmental offices responsible for environmental monitoring and for controlling *U. cordatus* harvesting have not made a practice that considers the local ecological knowledge or the local socioeconomic reality into consideration - which could explain the generally low effectiveness of the policies (Nordi et al., 1994; Alves et al., 2005, Firmo et al., 2011). As recorded in this study for the crab *Ucides cordatus*, the accumulated empirical knowledge of the human populations that use this fishery resource can furnish important subsidies to improve regulations designed to rationalize the harvesting and management of

natural stocks of this species (Firmo et al., 2012). Thus, the integration of traditional knowledge with scientific knowledge plays a critical role in the development and execution of management plans (Cortês et al., 2014).

4. Conclusions

The present study is the first report of the ethnoecology of *Ucides cordatus* in the São Francisco River Estuary. We found that the local populations have a substantial LEK about *Ucides cordatus* population and body sizes, life cycle, sexual differentiation, behavior and habitat, which are in accordance with scientific literature. This high knowledge found in these populations are linked to three main factors: the fishery of the *Ucides cordatus* starts early in the fisherman's life and is passed along the generations, this activity is one of the main sources of income because the study area lacks of income alternatives, and the more knowledge the fishermen holds about biological and ecological of the crab aspects (e.g. habitat, life cycle, abundance, sexual differentiation), further improvement and optimization of fishery is achieved, which is crucial for their economic subsistence.

The knowledge and gathering practices applied by the local populations of the São Francisco River Estuary have important contributions for the conservation of the species and can serve as base for the formation of management and conservation plans for sustainable fisheries. For example, knowledge about the crab reproductive periods and about mangrove areas important for the crab conservation can aid in the definition of closed seasons and habitats. Additionally, the conservation knowledge in the used of the "small net" gathering technique suggests a re-examination of the Brazilian law that prohibits this method, specially for health integrity of fishermen that have long-term economic dependence on this activity.

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CAPÍTULO 4

**Population status and fishery potential of the mangrove
crab (*Ucides cordatus*) in the São Francisco
River Estuary (Brazil Northeast)**

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Population status and fishery potential of the mangrove crab (*Ucides cordatus*) in the São Francisco River Estuary (Brazil Northeast)

Abstract

Ucides cordatus is a semiterrestrial crab that lives only in mangrove areas and is considered a key species of these habitats. In the São Francisco River Estuary (Northeastern Brazil, 10° 30' 27"S, 36° 23'45"W) this crab is the second most economic-important mangrove fishery resource. Nevertheless, decreases in this species' stock have been reported since 2000, requiring assessments of the crab population for management purposes. This study aims to assess the population status and the fishery potential of *Ucides cordatus* in the mangroves of this estuary. Six different sites in a total of 30 km² of mangrove forests were sampled, and the number of *Ucides cordatus* burrows were counted and the diameters of burrow entrances measured. Results shows that the mean burrow size of *Ucides cordatus* was 56.82 ($\pm$ 12.19) mm, and that medium size crabs (40mm to 70 mm) are the most abundant. The mean crab density was 1.2 ($\pm$ 0.68) burrow.m⁻², from which the density of burrows from crabs in commercial size (0.85 $\pm$ 0.55 burrow.m⁻²) was significantly higher than those in non-commercial size (0.35 $\pm$ 0.21 burrow.m⁻²). In overall the São Francisco River Estuary mangroves showed a high potential for the crab fishery, but lower crab densities is a limiting factor for the fishery. We argued that this lower density is mainly caused by a high mortality of the crab that occurred in 2000, mangrove deforestation due to shrimp farming and also to a high fishery pressure on *U. cordatus*. We conclude that the areas of mangrove more appropriate for *U. cordatus* fishery are those which combined high mean crab size as well as high frequency and density of commercial crabs. On the other hand, mangrove areas appropriate for the conservation of *U. cordatus* are those with small mean size crab combined with high frequency and density of non-commercial crabs.

Key-words: *Ucides cordatus*, artisanal fishery, fishery management, population assessment.

1. Introduction

Mangroves are productive coastal ecosystems that form an ideal habitat for a variety of animals, including many fishery species (Barbier, 2000, Nagelkerken et al., 2008). An example of this is the mangrove crab *Ucides cordatus* (Linnaeus, 1763), a semiterrestrial crab that lives only in mangrove habitats, where it digs burrows in the sediment up to 2 m deep and show nocturnal habits (Holthuis, 1959; Costa, 1979; Alcantara-Filho 1978; Schmidt, 2006). This crab is distributed along the tropical and sub-tropical mangrove coasts of the eastern Americas from southern Florida to southern Brazil, in the Santa Catarina State (Bright and Hogue 1972; Melo, 1996).

Ucides cordatus is considered a key species of mangrove ecosystem for its high biomass, its role in nutrient cycling and in the trophic structure of these ecosystems (Wolff et al. 2000; Koch and Wolff 2002; Schories et al. 2003; Nordhaus et al. 2006). In Brazil, due to its large size and tasty meat, *U. cordatus* has been extensively exploited (Rodrigues et al., 2000) and holds a major socio-economic importance for artisanal fishery, constituting the economic base of many human coastal populations (e.g. Glaser and Diele 2004, Alves and Nishida, 2003; Alves et al. 2005; Passos and Di Benedetto 2005, Souto, 2007; Firmo et al. 2011, Santos et al., 2013). Despite their socio-economic importance, the population status and ecology of semi-terrestrial crabs is generally not well known, which often hampers the development of effective management strategies (Diele et al., 2005).

The large size of *Ucides cordatus* suggests that this species has a high vulnerability to exploitation as it is generally correlated with slow growth, high age at maturity, long-lived (>10 years), low reproductive output and low natural mortality (Pauly 1998; Jennings et al. 1998; Jennings et al. 1999, Diele and Koch, 2010). Declines of *U. cordatus* have been reported from many coastal regions of Brazil and were related to mangrove habitat destruction, diseases and overfishing (Maneschy 1993; Boeger et al. 2005, Diele et al., 2005).

Massive mortalities of *U. cordatus* have been reported by crab harvesters and biologists since 1997 throughout northeastern Brazil, from Ceará to Espírito Santo State (Boeger et al. 2005; Boeger, 2007) that have decimated local stocks (Alves and Nishida, 2003; Firmo et al., 2011). This mortality has generated considerable concern among specialists in regards to resulting environmental and socioeconomic impacts (Alves and Nishida, 2003; Firmo et al., 2011).

Considering this scenario, studies on the population status of *Ucides cordatus* on the coast of Brazil, such as population density and size of crabs, are extremely important for stock evaluation, estimation of population recovery and assessment of fishery potential (e.g. Hattori, 2006; Wunderlich et al 2008.). This information is extremely important to establish strategies for the sustainable use this crab, a major mangrove fishery resource in the northeastern Brazilian coast (e.g. Wunderlich et al., 2008).

In the São Francisco River Estuary (Northeastern Brazil, 10° 30' 27"S, 36° 23'45"W) *Ucides cordatus* occur along 30 Km² of mangrove forests and is the second most exploited mangrove fishery resource, constituting the major economic base for deprived human populations of eight coastal villages (Santos et. al., 2013, 2014). Despite its importance, decreases in this species' stock have been reported since 2000, both by local populations and research institutes (e.g. CEPENE, 2003; Santos et. al., 2013; Santos et. al., *not published*). Therefore, this study aims to assess the population status (population density and size of crabs) and the fishery potential of *Ucides cordatus* in the mangroves of this estuary, and thus to contribute with information to implement strategies for sustainable use and conservation of this important mangrove fishery resource.

2. Material and Methods

2.1. Study area

The São Francisco River is one of the most important Brazilian water resources and is considered the River of National Integration, draining seven states along its 2,863 km. The river basin (636,919 km²) is divided in four sub-regions from its nascent to its estuary: high, medium, sub-medium and low São Francisco (ANA, 2005). The estuary of this river is located in the low sub-region, on the boundary of Sergipe and Alagoas States (10° 30' 27"S, 36° 23'45"W) (Figure 1), in the Northeast of Brazil.

The study area corresponds to the southern part of the São Francisco River Estuary (State of Sergipe) (Figure 1) and covers approximately 192.35 km² and is part of the municipalities of “Brejo Grande” and “Pacatuba”. This estuary shows a mangrove extent of 30.1 km², which corresponds to about 16% of the study area (Santos et al., 2014). The study area is characterized by a remarkable lack of infrastructure, such as paved roads, hospital, health centre, schools and commercial stores. The inhabitants are deprived population composed of native residents whose income and subsistence depends on agricultural activities, aquaculture and mainly fishery, highlighting the fishery of the mangrove crab . A total of eight fishery villages are distributed on this area, characterized by artisanal fishery practices, using canoes and fishing methods as line, net and gathering of crabs and shellfishes (CEPENE, 2003). This area is part of a State Environmental Protected Area (APA “Litoral Norte”), a Conservation Unit of sustainable use whose objectives include the promotion of the socio-economic and sustainable development by activities that protect and conserve the ecosystems and the improvement of the life quality of the local population (Sergipe, 2004).

Figure 1. (a) Map of South America and Brazil indicating the location of the São Francisco River basin (adapted from ANA, 2005). (b) The São Francisco River basin with its four divisions (adapted from ANA, 2005). (c) A close-up of the São Francisco River Estuary, the study area.

2.2. Sample of *Ucides cordatus* burrows and population estimations

Six different sites of mangrove forests were sample (Figure 2). At each site two transects of 50 m from the channel edge towards the interior of the mangrove forest were delimited. The transects were arranged parallel to each other and separated by a distance of 5 m. Within the area bounded by transects, three quadrats of 5 x 5 m (25 m²) were delimited (e.g. Schmidt et al., 2008; Amaral et al., 2014). The first quadrant was at 5 m from the edge, the second at the 25 m and the third at 45 m. In each quadrat the geographical coordinates were recorded on a GPS (Global Positioning System, Garmin eTrex Venture HC), the dominant mangrove species were identified and mean stand stature (height) was estimated. A total of 18 quadrants were sample.

Within each quadrant the diameter of burrow entrances of *U. cordatus* was measured using a digital caliper. Only active galleries, identified by the presence of fluid mud, feces, and/or animal traces close to the opening, were considered (e.g. Sandrini-Neto and Lana,

2011). *Ucides cordatus* burrows are easily recognized in the field and broadly used as a proxy of crab density and size (Piou et al. 2009; Sandrini-Neto e Lana, 2011).

Figure 2. Land use and cover map of study area (São Francisco River Estuary), indicating the mangrove sample sites (S1, S2, S3, S4, S5 and S6).

Population estimations from burrow numbers and size have been used widely for mangrove crab species (e.g., Macintosh 1988; Warren 1990; Skov et al. 2002; Salgado Kent and McGuinness 2006), including *U. cordatus* (e.g. Alcantra-Filho, 1978; Alves e Nishida, 2003; Alves et al., 2005; Hattori, 2006; Schmidt et al. 2008; Wunderlich et al. 2008, Piou et al. 2009; Sandrini-Neto e Lana, 2011). Advantages of this methodology includes: speed and consequent increase in sample size; conducting non-destructive sampling, important when work involves endangered species and the possibility of obtaining measures of all individuals within sampling units (Schmidt et al., 2008).

Considering that each burrow of *U. cordatus* is inhabited by a single crab (Costa, 1979; Alves et al. 2005), the number of burrows within the quadrats in each mangrove site was used to estimate the crab density (number of burrow/m²), and the diameter of the burrow entrance used as a proxy crab size (e.g. Alcantra-Filho, 1978; Alves and Nishida, 2004; Alves et al., 2005; Hattori, 2006; Schmidt et al. 2008; Wunderlich et al. 2008, Piou et al. 2009; Sandrini-Neto and Lana, 2011). The data of crab burrow size was classified in eight size class: 20-30 mm, 30-40 mm, 40-50 mm, 50-60 mm, 60-70 mm, 70-80 mm, 80-90 mm and 90-100 mm; and histograms of the class size-frequency distribution were produced.

According to studies carried out by Schmidt (2006) and Schmidt et al. (2008), the legal minimum market crab size of 60 mm (IBAMA N° 034/03-N, 24.06.03) corresponds to a burrow diameter size of 51 mm. Therefore, the frequency and density of crabs in commercial size was determined by the frequency (%) and density (number of burrow/m²) of burrows with diameter size equal or larger than 51 mm, respectively. Similarly, the frequency and density of crabs in non-commercial size was determined by the frequency and density of burrows with diameter size equal or larger than less than 51 mm.

2.3. Statistical analysis

The data was tabulated and analyzed in *GraphPad Prism* and *Excel* software. The analysis was carried out considering the entire mangrove forest of the São Francisco River Estuary (all sampled sites) and in relation to each mangrove site, which were compared by statistical tests. Descriptive statistic as mean, standard deviation (SD) and frequency was calculated for crab burrow size and density. The normality of the data and homogeneity of variances were assessed by Kolmogorov–Smirnov and Bartlett tests, respectively. Most of the data passed in these tests, but when not and when the sample was large, we used the ANOVA, since this analysis remains consistent notwithstanding the lack of normality (Underwood,

1997; Sandrini-Neto e Lana, 2011). The statistics analysis ANOVA and Tukey's Multiple Comparison Test were carried out in order to compare the mean burrow diameter among the six sites of mangrove. The Kruskal-Wallis test (non-parametric ANOVA) and Dunn's Multiple Comparison Test were used to compare mean crab density among the six sites of mangroves, because of the small size of this sample data. The Test-T was used to compare if there is difference in the density of the commercial and non-commercial crab burrow sizes. The statistics analysis was carried out in the *GraphPad Prism* software.

3. Results

A total of 541 burrows of *Ucides cordatus* were measured and counted along the six mangrove sampled sites in the São Francisco River Estuary, counting a total of 450 m² of sampled mangrove area. In summary, all sampled sites were dominated by *Rhizophora mangle* and some sites also showed the occurrence of *Avicennia schaueriana*, *Laguncularia racemosa* or both (sites 2, 3, 4 and 6). Site 6 was the unique that recorded the mangrove associated species *Acrostichum aureum* and dead *L. racemosa* trees infested by termites, while site 5 showed a remarkable high density of rhizophores. Mangrove stands of short stature (height < 7 m) were recorded in sites 2, 3 and 6, while medium mangrove stand stature (height between 7 m and 15 m) recorded in sites 1, 4 and 5.

Considering all the six sampled sites, the overall mean burrow size of *Ucides cordatus* in the mangroves of the São Francisco River was 56.82 ($\pm$ 12.19) mm. Most of the crab burrows are in the class size of 50 to 60 mm (33.8%), followed by the class of 60 to 70 mm (24%) and 40 to 50 mm (22.6%) (Figure 2a). Thus, medium size crabs (40mm to 70 mm) are the most frequent in the mangroves of the São Francisco River Estuary. Burrows from large size crabs (70-80 mm: 8.32%, , 80-90 mm: 4.3% and 90-100 mm: 0.34%) and small

(20-30 mm: 0.34%, 30-40 mm: 5.5%) are less frequent in these mangroves, but the larger are more frequently than the smaller (Figure 3a).

Figure 3. Parameters of *Ucides cordatus* burrows in the mangroves of the São Francisco River Estuary. (a) Size-frequency distribution of *Ucides cordatus* burrow classes. (b) Frequency of the crab burrows in commercial and non-commercial sizes. (c) Density of the crab burrows in commercial and non-commercial sizes (** $p < 0.01$).

The comparison of the six mangroves sites indicated that mean crab burrow size significantly differed among some sites (ANOVA, $p < 0.0001$). Site 1 showed the highest mean burrow size, which significantly differed from all the other sites, excepted from site 2. On the other hand, site 6 showed the lowest mean burrow size, differing from sites 1, 2 and 5. The others sites (2, 3, 4 and 5) did not differed in mean burrow size (Table 1).

In regard to size-frequency distribution in the six mangroves sites (Figure 4), site 1, which recorded the highest mean burrow size (Table 1), also showed highest frequency of large crab burrows (70-80 mm: 17.07%, 80-90 mm: and 90-100: 14.6% mm: 4.87%) and the lowest frequency of small crab burrows (20-30 mm: 2.44%, 30-40mm: 2.44%). Moreover, this was the unique site that recorded all the class of crab burrow size. Sites 2, 3, 4 and 5 showed similar size-frequency distribution, with predominance of medium size crab burrows

(40-50 mm, 50-60 mm and 60-70 mm), but site 4 recorded the highest frequency of burrows between 50-60 mm (44.09%) (Figure 4). Site 6 although showed predominance of medium size crab burrows, the most frequent size class was of 40-50 mm (31%), differing from all the others sites (Figure 4).

Table 1. Parameters of *Ucides cordatus* burrows in the six sampled sites mangroves in the São Francisco River Estuary. (For mean crab burrow size $p < 0.0001$ and for densities, $p < 0.05$).

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Mean crab burrow size (mm)	64.06 (± 15.73)	58.96 (± 10.25)	56.33 (± 13.54)	56.19 (± 10.98)	57.17 (± 12.09)	51.76 (± 10.23)
Frequency of commercial crab burrow size (%)	80.48%	81.48%	70.37%	76.38%	69.23%	52.50%
Frequency of non-commercial crab burrow size (%)	19.52%	18.42%	29.63%	23.62%	30.77%	47.50%
Mean density of total crab burrows (burrow.m⁻²)	0.56 (± 0.21)	1.08 (± 1.1)	1.06 (± 0.70)	1.69 (± 0.66)	1.73 (± 0.51)	1.07 (± 0.06)
Mean density of commercial crab burrow size (burrow.m⁻²)	0.43 (± 0.23)	0.88 (± 0.87)	0.76 (± 0.64)	1.29 (± 0.55)	1.2 (± 0.42)	0.56 (± 0.11)
Mean density of non-commercial crab burrow size (burrow.m⁻²)	0.13 (± 0.06)	0.20 (± 0.24)	0.32 (± 0.26)	0.40 (± 0.14)	0.53 (± 0.23)	0.51 (± 0.08)

In overall, about 71.2% of the total sampled burrows are from crabs which are in commercial size (burrow size ≥ 51 mm), while 28.8% are from crabs that do not reached the commercial size (burrow size < 51 mm) (Figure 3b). Sites 1 and 2 recorded the highest frequencies ($>80\%$) of burrows from crabs in commercial size and the lowest of crabs in non-commercial size (Table 1). Sites 3, 4 and 5 showed intermediate frequencies (70% - 69%) of burrows from crabs in commercial size. The site 6 showed the lowest frequency of burrows from crabs in commercial size and the highest frequency of burrows from crabs in non-commercial size, thus strongly differing from all the other sites.

Figure 4. Size-frequency distribution of *Ucides cordatus* burrow classes in the six sampled sites of mangroves in the São Francisco River Estuary.

The overall mean crab density in the mangrove forests of the São Francisco River Estuary was $1.2 (\pm 0.68)$ burrow.m⁻². From this, the density of burrows from crabs in commercial size (0.85 ± 0.55 burrow.m⁻²) was significantly higher than the density of crabs in non-commercial size (0.35 ± 0.21 burrow.m⁻²) (T-Test, $p < 0.01$) (Figure 3c). Considering the total mangrove extent (30 km²), the study area showed, in February 2013, a mean total crab stock of about $3.6 \cdot 10^7$ individuals, from which $2.55 \cdot 10^7$ individuals are crabs in commercial size and $1.05 \cdot 10^7$ individuals are crabs in non-commercial size. Thus, the proportion of commercial size crab stock/non commercial size crab stock in the mangrove of the São Francisco River Estuary is 1 : 0.4.

The mean density of total, commercial and non-commercial crab burrows did not differ statically among the six sites (Kruskal-Wallis test, $p < 0.05$). However, sites 4 and 5 showed higher values of total and commercial mean densities than the sites 1, 2, 3 and 4. The lowest values of mean density was recorded in the site 1 (Table 1). Site 4 was the unique that

showed similar values of commercial and non-commercial crab burrow density (Table 1), recording a proportion of approximate 1 : 1.

4. Discussion

4.1. Population structure

The value of mean *Ucides cordatus* density (1.2 burrows. m⁻²) recorded in this study was similar or lower than those recorded in other mangroves along the Brazilian coast (Table 2). The most similar values were recorded in mangroves located on the north coast, in Amapá (e.g. Amaral et al., 2014) and in the south coast in Santa Catarina (e.g. Branco, 1993). It is interesting to note that we registered lower values than those found in mangroves on the northeast coast, the region where the study area is located. The low values of mean crab density recorded in the mangroves of the São Francisco River Estuary can be attributed to a high mortality of the crab in this area which started in 2000, as reported by local fisherman (e.g. Santos et al. *not published*). This high mortality of *Ucides cordatus* in the study area is also supported by data of the crab production which showed a high decrease since 1999 (e.g. CEPENE, 1999, 2000, 2001, 2002, 2003). The same evidence of low crab density related to crab mortality was also observe by Alves and Nishida (2004) in mangroves at the Brazilian Northeast. Additionally, it is remarkable that the *U. cordatus* density can vary between different mangrove areas as a result of their degradation or as a result of a higher incidence of this extractive feature (Pinheiro and Fiscarelli, 2001), as well as due to intrinsic factors of a particular mangrove forest (primary productivity, patterns of larval recruitment, among others) (Conti et al., 2010). Since in the study area shrimp farming is the main impact causing deforestation of mangroves (Santos et. al., 2004), and the fishery of *U. cordatus* by the local communities is very high (Santos et al. *not published*), these two factors can also contribute to the lower densities recorded in the present study. Moreover, in general, recent papers have

registered smaller crab densities than the older studies, probably revealing that the crab population has been overfished, mainly due to unsustainable practices (Conti et al., 2010). The reduction of the crab size, weight and abundance in various mangrove areas in Brazil reveals the great pressure to which the *U. cordatus* crab population has been subject (Goes et al., 2010).

The mean size of *Ucides cordatus* recorded in this study (56.82) was in overall similar to those recorded in the northeast coast, lower than the north and higher than the southeast and south coast (Table 2). Here we found a dominance of adult medium size crabs (40mm to 70 mm), mainly from the class of 50 to 60 mm. This pattern was also recorder in other studies of *Ucides cordatus* in Brazilian mangroves (e.g. Passos and Beneditto, 2004; Diele et al., 2005) and is in accordance with the survival curve for the species, which is characterized by high survival in intermediate age classes/sizes, followed by a decrease when close to longevity/maximum size (Leite et al. 2012). Additionally, we found more frequency of larger crabs than the smaller (Figure 3a). High frequency of large crabs is frequently found in large, long-living species, such as *U. cordatus*, where crabs accumulate in larger size classes as growth decreases with age (Hartnoll 1982; Hartnoll and Bryant 1990).

Differences in mean crab burrow size and in the size frequency were detected among the mangrove sites. The highest and significant difference in crab size was found between site 1, the mangrove area located farthest from the estuary mouth (Figure 2), which showed the largest crabs, and site 6, the most close to the estuary mouth (Figure 2), which showed the smallest crabs (Figure 1b, Table 1). These sites showed strong differences in vegetation composition, for example, site 1 is a mono-specific mangrove forest of *Rhizophora mangle*, while site 6 is dominated by *R. mangle* and *Laguncularia racemosa*, and was the unique site to recorded the mangrove associated species *Acrostichum aureum* and dead *L. racemosa* trees

infested by termites. Therefore, differences in crab size and size frequency between these sites can be attributed to differences in vegetation composition.

Table 2. Density and mean size of *Ucides cordatus* recorded by the literature in mangrove forests of Brazil.

Brazilian Region	State	Mean density (burrows or crabs. m ⁻²)	Mean size (mm)	Period	Reference
North	Amapá	1.09	64.35	2008-2010	Amaral et al. (2014)
	Pará	6.09	52.1	2004	(Piou et al., 2009)
	Pará	1.7	61 [*] , 55 ^{**}	1997-1998	Diele et al. (2005)
Northeast	Paraíba	1.7	56.6 [*] , 50.5 ^{**}	2000-2001	Alves and Nishida (2004)
	Ceará	4.75	60.3 [*] , 56.9 ^{**}	1973-1975	Alcântara-Filho (1978)
Southeast	Espírito Santo	2.5	48.9	2004-2005	Conti et al. (2010)
	Espírito Santo	3.7	54.6	1998-1999	Goes et al. (2010)
	São Paulo	1.8 [§]	45.9 [§]	2005	Hattori (2006)
South	Paraná	1.35 [†] , 0.86 ^{††}	-	2007	Sandrini-Neto and Lana (2011)
	Santa Catarina	1.11	-	1987-1990	Branco (1993)
	Santa Catarina	2.02	68 [*] , 58.7 ^{**}	2002-2003	Wunderlich et al. (2008)

^{*} Male, ^{**} Female, [§] sampled in *Rhizophora mangle* forests, [†] Commercial size, ^{††} Non-commercial size.

The vegetation type was significantly correlated to mangrove crab characteristics, abundance and weight/size (Gomes et al., 2013). Differences in food availability (leaf litter) and/or quality could have caused differential growth rates and thus crab sizes among areas (Diele et al., 2005). *Ucides cordatus* preferentially created their burrow entrances closed to *R. mangle* prop roots (Piou et al., 2009). Presence of *A. germinans* and *L. racemosa* in the neighborhood was not found to favour big sizes and large numbers of crab burrows (Piou et

al., 2009). Thus, since *U. cordatus* mainly feed on mangrove vegetation litter, the occurrence in site 6 of *L. racemosa*, the mangrove associate *Acrostichum aureum*, and dead trees could caused reduction on food availability (leaf litter) and quality, leading to the high frequency of smaller crabs. The others mangrove sites (2, 3, 4 and 5) did not differed in mean burrow size (Table 1) and showed very similar vegetation composition, with *Rhizophora mangle* as the dominated species. These results confirm the influence of the vegetation composition on the *U. cordatus* population structure, as stated by Gomes et al. (2013).

We do not recorded significant differences in the crab density among the mangrove sites (Table 1). Nevertheless, it is important to highlight that the mangrove site 1, which recorded the largest crab sizes, also recorded the lowest density (Table 1). This low density with dominance of large crabs could be attribute to the occurrence of mono-specific mangrove forest of *Rhizophora mangle*, the vegetation composition found in the preferred habitat of *U. cordatus* (e.g. Diele et al. 2005; Piou et al. 2009). In this type of habitat, large crabs apparently exclude smaller ones from preferred habitats (Piou et al. 2009; Sandrini-Neto and Lana, 2011), thus favoring the dominance of the largest crabs.

Conti et al. (2010) found that highest crab density is linked to high numbers of juvenile crabs, which was found on the upper estuary and correlated with lower salinities . The present study also recorded similar founds to Conti et al. (2010), since in the site 6 was recorded the highest frequency of small crabs (juvenile) at high density (Table 1, Figure 4). Moreover, the mangrove site 6 is the closest to the river mouth, thus receive more freshwater, showing lower sanity, and was classified by Semesato (2004) as a oligohaline area (salinity 0.5 to 5). The optimal salinity for *Ucides cordatus* is from 25 to 30 (Oliveira, 1946), thus, it seems that large crabs preferably occupies the areas with this optimal salinity, and consequently exclude small crabs to areas of lower salinity, a similar pattern found for the large crabs occupying the preferably mangrove habitat related to vegetation composition, in

which the intra-specific competition is the main factor (e.g. Diele et al. 2005; Piou et al. 2009; Sandrini-Neto and Lana, 2011).

4.2. Fishery Potential

In overall the study area show a high potential for the fishery of *Ucides cordatus*, since most of the crabs are in commercial size, with a higher density of commercial size crabs than the non-commercial (Figure 2b, c). Very similar result of high *U. cordatus* fishery potential was recorded by Wunderlich et al. (2008), in mangroves at Santa Catarina State (south Brazil). Although it was estimated a large stock of commercial crabs ($2.55 \cdot 10^7$ individuals) in the São Francisco River mangroves, it is important to highlight that this resource is the second most explored in this area, constituting the main base of the local subsistence economy (Santos et al. *not published*). Thus, the pressure on this resource is very high, requiring adequate management strategies for the sustainable use. Another important point is that it was recorded a lower overall crab density when compared to other Brazilian mangrove areas, which could be related to crab mortality and overfish. Considering these features, it is important to establish management strategies for conservation and a sustainable fishery of the *Ucides cordatus* in the São Francisco River Estuary.

Due to the reduced growth rate of *U. cordatus* and intense extraction of this resource, it is necessary laws of closure, the intensification supervision and proper management of its natural populations, in order to conserve the species and ensuring the continuity of the extraction process (Pinheiro and Fiscarelli, 2001). In this view it is crucial the identification of mangrove areas more suitable to the fishery and others for conservation, in order to allow the conservation of adults crabs for reproduction and the non-commercial size crabs grow to reach the commercial size.

For example, sites 1 and 2 recorded the highest frequencies of burrows from crabs in commercial size, and sites 3, 4 and 5 showed intermediate frequencies (Table 1), indicating that they are the more potential mangrove areas for crab fishery. From these, the sites 4 and 5 are the most important areas for fishery, since they combined higher values of mean crab density and density of crabs from commercial size plus higher values of mean crab size. On the other hand, the site 6 showed the lowest frequency of burrows from crabs in commercial size and the highest frequency of burrows from crabs in non-commercial size, thus it is a mangrove area more appropriate for conservation of the *U. cordatus* populations, instead of fishery.

Corroborating to our finds obtained in another study (Santos et al. *not published*), the villages that most exploit *U. cordatus* in the study area, use mangroves located in site 1, 2, 3 and 4, which showed high potential for fishery. For example, the first most crab producer village (Carapitanga) mainly use mangroves located in site 4, the area which showed a remarkable high frequency of crabs in the class size of 50 to 60 mm (Figure 4) and the highest density of commercial crabs (Table 1). The second most producer village (Oitizeiro), mainly use mangroves of site 1 and 2; and the third producer village (Aracaré) exploits *U. cordatus* on mangroves of the site 2 and 3 (e.g. Santos et al. *not published*). Nevertheless, most attention should be directed to site 1, because although it showed the highest mean crab size, it also recorded the lowest density. Therefore, among the sites that showed potential for fishery, site 1 should be the less exploited. An alternative for this, is the use of the mangrove site 5, an area with that combined high mean crab size and density, instead of the exploitation of the crab in site 1.

5. Conclusion

We concluded that the mangrove vegetation composition influence on the *U. cordatus* population structure. Here we found larger crabs in mangrove areas of mono-specific mangrove forest of *Rhizophora mangle*, or dominated by this mangrove species. The presence of the mangrove associate *Acrostichum aureum* and dead trees of *L. racemosa*, was linked to the occurrence of smaller crabs. The main factor causing these pattern seems to be intra-specific competition, in which large crabs exclude smaller ones from the preferably habitat (e.g. Diele et al. 2005; Piou et al. 2009; Sandrini-Neto and Lana, 2011).

In overall the São Francisco River Estuary mangroves show a high potential for the fishery of *Ucides cordatus*. Nevertheless, this study area showed lower densities of *U. cordatus* than other mangrove Brazilian areas. We argued that this lower density is mainly caused by a high mortality of the crab that occurred in 2000, mangrove deforestation due to shrimp farming and also to a high fishery pressure on *U. cordatus* by the local populations. This scenario reveals the need for management strategies for the conservation and sustainable management of *U. cordatus*. Therefore we conclude that the areas of mangrove more appropriate for *U. cordatus* fishery are those which combined high mean crab size as well as high frequency and density of commercial crabs. On the other hand, mangrove areas appropriate for the conservation of *U. cordatus* is those with small mean size crab combined with high frequency and density of non-commercial crabs.

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CAPÍTULO 5

**Multi-criteria evaluation for the conservation and fishery
of the mangrove crab *Ucides cordatus*: a case study in the
São Francisco River Estuary (Northeastern Brazil)**

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Multi-criteria evaluation for the conservation and fishery of the mangrove crab *Ucides cordatus*: a case study in the São Francisco River Estuary (Northeastern Brazil)

Abstract. Mangroves are productive coastal ecosystems that form an ideal habitat for many fishery commercial species, as the mangrove crab *Ucides cordatus*. In Brazil this crab hold a major socio-economic importance for artisanal fishery, but declines on its productivity has been putting this fishery at risk. In order to contribute to establish strategies for a sustainable fishery of this species, this study determined the more suitable mangrove areas for the conservation and fishery of the crab *Ucides cordatus* in the São Francisco River Estuary (Northeastern Brazil), using a Multi-Criteria Evaluation (MCE). We applied the MCE Decision Support in IDRISI Selva, considering the Weighted Linear Combination and the Analytical Hierarchy Process. A total of ten criteria were used: five biotic of the crab population parameters, three related to land use and cover and two social factors. To produce the maps of each criterion, it was applied remote sensing techniques using CBERS and SPOT images (e.g. vegetation index, pansharpening, supervised classification, distance operators) and field data. The mangrove areas more suitable for the conservation of *Ucides cordatus* (9.4 km²) are those more close to the river mouth, showing high density and frequency of crabs in non-commercial size, low density of crabs in commercial size, small crabs and low degree of use for the crab fishery. On the other hand, the mangroves more suitable for the crab fishery (10.2 km²) are those located far from to river mouth, showing high density and frequency of crabs in commercial size, low density of crabs in non-commercial size, big sized crabs, medium to high degree of use for crab fishery and are more close to the fishery villages. These information and maps of suitability can aid government agencies in delineating extractive and fishery exclusion areas, as stated by the Proposal of a National Management Plan for this crab, in order to achieve a sustainable fishery as well as recovery and maintenance of the resource stock.

Key words: Geoprocessing, Analytical Hierarchy Process, artisanal fishery, socio-ecological systems, conservation, crustaceans.

1. Introduction

Mangroves are coastal forests that inhabit saline tidal areas along sheltered bays, estuaries, and inlets in the tropics and subtropics throughout the world, where they fulfill several ecological, environmental and socio-economic functions (Barbier et al., 2011, FAO, 2007). From them, it is remarkable the role of mangrove as habitat for many fishery commercial species, such as fish, crabs, shrimps and mollusks, thus supporting small-scale fishery along the world's (sub)tropical coast (FAO, 2003, Wielgus et al. 2010, Rönnbäck, 1999, Walters et al., 2008). Nevertheless, due to pressures from anthropogenic activities and lack of awareness or of perseverance in conservation and management strategies already implemented and/or proposed (Farnsworth and Ellison, 1997; Primavera, 2000; Kovacs, 2000; Armitage, 2002; Dahdouh-Guebas et al., 2002, 2005b; Feagin et al., 2010, Satyanarayana et al., 2013; Santos et al., 2014), mangrove forests are disappearing worldwide at rates of 1 - 2% per year (Valiela et al., 2001; Alongi, 2002; FAO, 2003; Primavera, 2006; Duke et al., 2007). As a consequence, this loss has been generated negative impacts in small-scale mangrove fisheries, in addition to high fishery pressure, causing decrease in the fishery yield and stocks (e.g. Cergole et al. 2005, Mendonça et al., 2010). For the coastal fisheries of developing countries, this is aggravated by coastal habitat degradation and widespread poverty in coastal communities (Andalecio, 2010).

From a diversity of fishery resources exploited in the mangrove environment, crabs are among the many commercially important species caught throughout the tropics (Macnae, 1974; Dall et al., 1990). In Brazil, the mangrove crab *Ucides cordatus* (Linnaeus, 1763), a semiterrestrial crab that lives only in mangroves and a keystone species of this ecosystem (Melo, 1996, Schories et al. 2003), is a major socio-economic important species for artisanal fishery, mainly in the Northeast coast of Brazil where it has been extensively exploited by local and traditional human populations (e.g. Fiscarelli and Pinheiro, 2002; Glaser, 2003;

Glaser and Diele 2004, Alves and Nishida, 2003; Alves et al. 2005; Passos and Di Benedetto 2005, Souto, 2007; Firmo et al. 2011, Magalhães et al., 2012; Santos et al., 2013; Cortês et al., 2014). Despite its importance, declines of *U. cordatus* have been reported in many coastal regions of Brazil and were related to mangrove habitat destruction, diseases and overfishing (Boeger et al. 2005, Diele et al., 2005). This crab species is included in the Brazilian National List of aquatic invertebrates species overexploited or threatened of overexploitation (e.g. Brasil, 2004) and with risk to get in extinction (Pinheiro and Rodrigues, 2011). This highlights the need for management strategies that allow the conservation of the resource in a sustainable fishery approach, as stated by the Proposal of a National Management Plan for this species, with the delineation of extractive and fishery exclusion areas (Brasil, 2011, Pinheiro and Rodrigues, 2011).

Considering this scenario, resource allocation for use or conservation, are also prime candidates for analysis with GIS and remote sensing techniques (Estman, 2012a). In the case of Socio-Ecological Systems (SES), as in fishery systems, where natural, human, and management systems have a complex interaction (Charles, 2001), several criteria will need to be evaluated for conservation and fishery management purposes. Therefore, it is crucial the understanding of the interrelationships among the various parts of the SES (Griffis and Kimball, 1996; Legendre and Legendre, 1983), requiring the developing of analytical and operational evaluation tools for decision-making (Andalecio, 2010) that include all of these parts and aspects. In these cases which involve multidisciplinary knowledge bases, a GIS procedure called Multi-Criteria Evaluation (MCE) is the more appropriate (Huang et al., 2011) to achieve conservation and management use proposes. MCE provides a systematic methodology to combine the inputs with cost/benefit information and stakeholder views to rank project alternatives (Huang et al., 2011). MCE have demonstrated their utility in many environmental issues that link economic, environmental, cultural and technical issues of

management (Abu-Taleb, 2000; Makowski et al., 1996, Andalecio, 2010). Despite its importance, the application of multi-criteria decision models to fisheries management is relatively scarce during the last 10 years (Andalecio, 2010).

In the São Francisco River Estuary (Sergipe State, Northeastern Brazil,) *Ucides cordatus* is the second most important mangrove fishery resource (Santos et al., 2013). However, decreases in this species' stock have been reported since 2000, requiring the definition of mangrove areas more suitable for the conservation and fishery of this crab, in order to maintain the natural stock of the resource and a sustainable fishery. This study aims to determine the most suitable mangrove areas for the conservation and fishery of the crab *Ucides cordatus* in the Estuary of the São Francisco River, using a MCE analysis, and considering a perspective that minimize the restrictions on the fishing and allow a socio-ecological sustainable fishery of this crab.

2. Material and Methods

2.1. Study area

The study area is part of the São Francisco River, one of the most important Brazilian water resources, and is located in the coastal zone of the Sergipe State (Northeastern Brazil) (Figure 1). The study area corresponds of the southern part of the São Francisco River Estuary (municipalities of “Brejo Grande” and “Pacatuba”) (10° 30' 27"S, 36° 23'45"W) and covers approximately 192.35 km². This estuary shows a mangrove extent of 31.9 km², which corresponds to about 16% of the study area (Santos et al., 2014). Other land cover and uses presented are: sandy coastal vegetation , aquaculture and agriculture (Santos et al., 2014). A total of eight fishery villages are distributed in this area, where fishery in the mangrove areas, specially of the crab *Ucides cordatus*, is the main economic subsistence base for the local

populations (Santos et al., 2013). The crab fishery in this mangroves is responsible for almost all yield of *Ucides cordatus* in the entire state of Sergipe (Brasil, 2011).

Figure 1. (a) Map of South America and Brazil indicating the location of the São Francisco River basin (adapted from ANA, 2005). (b) The São Francisco River basin with its four divisions (adapted from ANA, 2005). (c) A close-up of the São Francisco River Estuary, the study area.

2.2. Multi-Criteria Evaluation (MCE): objectives and criteria

In this study we applied a Multi-Criteria Evaluation (MCE), in order to determine the most suitable mangrove areas for the conservation (objective 1) and fishery (objective 2) of the crab *Ucides cordatus* in the São Francisco River. For this, we applied the MCE Decision Support tool in the *IDRISI Selva* and considered the Weighted Linear Combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average (Estman, 2012a).

For the objective 1, a total of nine factors were used in the MCE, including four biotic criteria related to the population parameters of the crab *Ucides cordatus*: 1) frequency and 2)

density crabs in non-commercial size (crab with carapace width < 60 mm), 3) density of crabs in commercial size (crab with carapace width ≥ 60 mm) and 4) mean crab size; three factors related to land use and cover: 5) mangrove vegetation types, 6) distance of mangroves from fishery villages and from 7) shrimp farms, and finally, two social parameters: 8) degrees of mangrove importance for crab conservation and 9) degrees of mangrove use for crab fishery, both according to the view of the local fisherman.

For the objective 2, a total of eight factors were used in the MCE, including four biotic criteria related to the population parameters of the crab *Ucides cordatus*: 1) frequency and 2) density crabs in commercial size, 3) density of crabs in non-commercial size and 4) mean crab size; two factors related to land use and cover: 5) mangrove vegetation types and 6) distance of mangroves from fishery villages; and finally, two social parameters: 7) degrees of mangrove importance for crab conservation and 8) degrees of mangrove use for crab fishery, both according to the view of the local fisherman. For both objectives, as a constraint, i.e., a boolean criteria that constrain (i.e., limit) the analysis to particular geographic regions (Estman, 2012b), we considered the polygons of the mangroves areas of the study site.

2.3. Production of maps of the MCE's criteria

In order to carry out a MCE, it is necessary that the criteria under analysis must be in a spatial data, as maps of images. Therefore, a map or image, in raster format, of each factor and constrain was produced by different geoprocessing and remote sensing techniques in the IDRISI software software (Figure 2). The initial geodatabase for this was a land use and cover map of the study area produced in our previous study (e.g. Santos et al., 2014) based on the pansharphing and visual and supervised classification of satellite remote sense images (Table 1). In this map, a Boolean analysis (reclassification to two class wherein for the class of interest is attributed the value 1, and all other classes are grouped in one single class with the

value 0) was used to produce a map of the mangrove areas, thus constituting the constraint of the MCE.

For the production of the maps of the crab population parameters, the map of the mangrove areas was submitted to a group analysis and reclassification, and six areas of mangrove were discriminated. The group analysis identifies contiguous groups of pixels in an image, thus delimiting areas with boundaries of geographic similarity (Esatman, 2012a). A field work was carried out wherein these six areas were sampled in order to collect the crab population parameters as diameter of the crab burrow entrances and number of burrows. The methodology applied for this sample is detailed described in the chapter 4 of this thesis. The number of burrows was used to estimate the crab density (number of burrow/m²), and the diameter of the burrow entrance used as a proxy crab size (e.g. Alcantra-Filho, 1978; Alves and Nishida, 2004; Alves et al., 2005; Hattori, 2006; Schmidt et al. 2008; Wunderlich et al. 2008, Piou et al. 2009; Sandrini-Neto and Lana, 2011). These data were statistically analyzed (see chapter 4) and the final parameters of the crab population structure were determined: mean crab size, frequency and density of crabs in commercial and non-commercial sizes. These parameters were spatialized matching the six areas of mangrove where they were collected, by a reclassification function in IDRISI and thus producing the maps of the maps of the crab population parameters.

In order to produce the maps of the two social parameters, an ethnoecological and social-economic survey was carried out in five fishery villages of the study area (see chapter 2 and 3), wherein local fisherman were asked about their opinion on which mangrove areas are important for the conservation of the crab *Ucides cordatus* and which are those used to fishery this crab. The percentage of respondents that indicated each mangrove area was calculate and used to determine categorical class (*low, medium, high* and *very high*) of degrees of mangrove

importance for crab conservation and use for crab fishery. These class were spatialized by the reclassification function using the map of mangroves submitted the group analysis.

The images of distance from fishery villages and from shrimp farms were produced by the application of the *distance operation* in IDRISI GIS Analysis using the map of land use and cover and the polygons of the villages and shrimp farming, respectively. Finally, for the production of the map of mangrove vegetation types, the normalized difference vegetation index (NDVI) was calculated using the CBERS-2B images (Table 1). The NDVI index is based on the spectral properties of green vegetation and is an indicator of primary productivity, vegetation biomass, health condition and canopy closure (Giri et al. 2007; Ruiz-Luna et al. 2010, Satyanarayana et al. 2011). Firstly, the images were submitted to atmospheric and radiometric corrections (e.g. Barbosa et al., 2011) and after geometrically corrected. Then the NDVI image was calculated using the red and near infrared bands, in the IDRISI module *image processing, vegindex*. Finally, the NDVI image was reclassified using NDVI ranges and four classes of mangrove vegetation types were discriminated, which was supported by field data about this vegetation.

Table 1. Features of the satellite images used in the study.

Satellite	Sensor	Spatial resolution (m)	Bands	Date	Path-Row
CBERS-2B	CCD	20	Blue, red and infra-red	05/14/2008	147-112
SPOT-5	HRG2	2.5	PAN	05/14/2008	731-371

Figure 2. Summary of the geoprocessing techniques applied to produce the maps of the criteria used in the multi-criteria evaluation.

2.4. Final steps of the (MCE): criteria standardization, Analytical Hierarchy Process (AHP) and Weighted Linear Combination (WLC)

After the elaboration of the maps or images of each criterion, they were standardized in a numeric range of 0 to 255. In IDRISI, the module named FUZZY is provided for the standardization of quantitative factors using a whole range of fuzzy set membership functions (Estman, 2012a). The fuzzy function was used to standardize the quantitative criteria such as crab population parameters, distance from fishery villages and shrimp farms. The qualitative criteria such as mangrove vegetation types, degrees of mangrove importance for crab conservation and mangrove use for crab fishery were standardize using the reclassification function, wherein knowing the relative suitability of each class, they were rescaled into the range 0-255 (e.g. Estman, 2012b).

The next step of the MCE was weighting the factors for aggregation, and it was carried out in the module WEIGHT of IDRISI, which utilizes a pairwise comparison matrix, technique developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP) (e.g. Estman, 2012a). Factors are compared two at a time in terms of their importance relative to the stated objective and ratings are provided on a 9-point continuous scale. The pairwise comparison matrix was completed by the consultation of specialists in the approach of the research. After all possible combinations of two factors are compared; the module calculates a set of weights, corresponding to one weigh for each criterion (e.g. Estman, 2012b).

Finally, the weighted factors and constraint were aggregated using the Weighted Linear Combination (WCL), a method that multiplies each standardized factor map (i.e., each raster cell within each map) by its factor weight and then sums the results. This result is then multiplied by each of the constraints in turn to "mask out" unsuitable areas (e.g. Estman, 2012a). The final map produced is a raster image raging from 0 (unsuitable areas) to 255

(most suitable areas), this image was then reclassified to categorical classes of suitability of the mangroves for the conservation and for the fishery of the crab *Ucides cordatus*. The area of each class was also determined.

3. Results and discussion

3.1. Maps and importance of the criteria for *Ucides cordatus* conservation and fishery

Figures 3, 4 and 5 shows the maps of the biological, land use/cover and social criteria, respectively, used in the MCE analysis, and the table 2 the weights of them derived by the AHP, which shows the degree of importance of each criteria for the definition of the two MCE objects. The AHP is a method of scaling ratios based in a pairwise comparison matrix (Saaty, 1980, 2001) which structures a problem into a hierarchy then the weights of the criteria are determined through pairwise comparisons (Saaty, 1980) according to preference, importance or likelihood (Peterson et al., 1994).

For both objectives, determine the most suitable mangrove areas for the conservation and fishery of the crab *Ucides cordatus*, the biological criteria related to the crab population parameters were those that showed the highest weights (Table 2). For the conservation purpose, the density and frequency of crabs in non-commercial size were the most important factors (Table 2), while density and frequency of crabs in commercial size were the most important for the fishery purpose. The maps of these parameters show that the density and frequency of non-commercial crabs increase in the direction of the São Francisco River mouth, and consequently, the smallest crabs are found in the mangroves areas near to the river mouth (Figures 4a, 4c, 4e). By the contrary, the density and frequency of crabs in commercial size increase in the opposite direction, where higher densities and frequency are found far from the estuary mouth and in intermediate areas, in which the biggest crabs are more found (Figures 4a, 4c, 4e). Population parameters of fishery resources are among the most important

indicators for fishery management, because they are directly related to the available resource stock, giving estimative of the amount of crabs available for fishery (crabs commercial size) and those that should be conserved and not fished (crabs in non-commercial size) (e.g. Hattori, 2006; Wunderlich et al., 2008).

While the development of performance criteria and indicators for fisheries management requires technical information, Chong (2000) emphasized that the interest, willingness and commitment of the people or the community are also imperative in the sustainable management and conservation of fisheries and other coastal resources (Andalecio, 2010). Thus, the inclusion of social criteria in MCE analysis, as data related to the view and knowledge of local population, are of importance considering the socio-ecological dimension of the *Ucides cordatus* fishery in mangrove areas. For both objective of the present study, the social criteria showed low to intermediate weights, wherein the degrees of mangrove use for crab fishery was considered more important than the degrees of mangrove importance for crab conservation (Table 2). The maps of these criteria show that the mangrove areas more close to the river mouth are those with low use to the crab fishery and with medium importance to the crab conservation (Figures 5a, 5b). On the other hand, the areas far from the estuary mouth are more exploited and considered by the locals of major importance for the crab conservation (Figures 5a, 5b). Here it is also important to point out that these areas are the more close to the fishery villages.

From the land use and cover criteria, the distance of mangroves from fishery villages (Figure 4c) was the most important, mainly for the fishery purpose, recording the third highest weight (Table 2). For this purpose, the distance of mangroves from fishery villages it is extremely important for the delineation of the most suitable mangrove areas for fishery, because in the study area most of the fisherman reaches the mangrove areas by feet or by canoe paddle. Thus, the local populations use the mangrove areas more close to the villages

where they live to fish the crab *Ucides cordatus* (Santos et al., 2013). Based on this, we considered that the suitability of the mangrove areas for the crab fishery decrease with the distance from the fishery villages. On the other hand, the suitability of the mangrove areas for the crab conservation increase with the distance from the fishery villages. Corroborating, Duarte et al. (2014) have found that mangrove areas, in the Southeast Brazil, with easy access by fishermen due to the proximity to the urban areas where their live, were those that showed the highest crab.

Lowest weights were given to mangrove vegetation types and distance of mangroves from shrimp farms (Table 2). In relation to the distance of mangroves from shrimp farming (Figure 4d), we considered that the suitability for the crab conservation increase with this distance, since the more distant areas are more protected from the impacts of this activity, such as mangrove deforestation and water pollution. Aquaculture is one of the most controversial and considered one of the largest threats to mangroves (Alongi, 2002; Primavera, 2006), mainly because this activity have been developed without adequate management, which can cause environmental impacts such as: mangrove loss, introductions and transfers of species, spread of parasites and diseases, misuse of chemicals, and release of wastes (Primavera, 2006; Santos et al., 2014).

In relation to mangrove vegetation types (Figure 4b), which is based on the values of NDVI (Normalized Difference Vegetation Index) exhibited by the mangroves, an indicator of the green biomass and vegetation quality (Giri et al. 2007; Ruiz-Luna et al. 2010, Satyanarayana et al. 2011), the mangrove suitability to the crab conservation and fishery are lower in the lowest values of NDVI (mangrove types 1 and 2) and higher in the highest values of NDVI (mangrove types 3 and 4). Mangrove type 1 ($0.2 \leq \text{NDVI} < 0.3$) are mangroves with exposed sediment, herbaceous vegetation (*Juncus* sp.) and *Acrostichum aureum* patches. Type 2 ($0.3 \leq \text{NDVI} < 0.45$) shows sparse mangrove vegetation with occurrence of the true mangrove

species (*Rhizophora mangle* L., *Avicennia schaueriana* Stapf and Leechman ex Moldenke, *A. germinans* (L.) Stearn, *Laguncularia racemosa* L.), few typical species of freshwater environments such as *Annona glabra* L. and *Montrichardia arborescens* (L.) Schott scattered within the true mangrove vegetation. This type mainly occurs near to the mouth of the estuary (Figure 5b). Mangrove types 1 and 2 show less abundance of green biomass, thus have less food available for *U. cordatus* which prefers to feed on *R. mangle* leaves (Nordhaus, 2004, Piou et al, 2009).

Mangrove type 3 ($0.45 \leq \text{NDVI} < 0.57$) exhibits dense canopy cover, with the dominance of the mangrove species *R. mangle*, but show small gaps or spaces in the canopy cover and it constitutes the dominant habitat in the study area. In this mangrove it was recorded the presence of some stands with the largest structural development in the study area, showing trees of *R. mangle* reaching heights up to 20 m (Santos et al., 2014). Mangrove type 4 ($0.57 \leq \text{NDVI} < 0.64$) shows dense canopy cover without gaps/spaces and occurrence of dense patches of *A. aureum* within the true mangrove vegetation. The types 3 and 4, which show the highest NDVI, are those with high green leaves biomass available for the crabs feed, thus they were considered the types more suitable for the crab conservation and fishery. The vegetation type is significantly correlated to population characteristics of *Ucides cordatus*, as density and weight/size (Gomes et al., 2013). Tree-species composition can have a significant effect on the habitat partitioning of the crab sizes (Wunderlich and Pinheiro, 2012), and the crab abundance is related to the presence of well-structured and well-preserved mangrove areas (Duarte et al., 2014). Differences in food availability (leaf litter) and/or quality could have caused differential growth rates and thus crab sizes among areas (Diele et al., 2005).

Table 2. Weights derived by calculating the principal eigenvector of the pairwise comparison matrix in the Analytical Hierarchy Process (AHP).

Type of criteria	Criteria	Conservation Weights	Fishery Weights
Crab population parameters	Density of crabs in non-commercial size	0.30	0.02
	Density of crabs in commercial size	0.17	0.27
	Frequency of crabs in non-commercial size	0.24	–
	Frequency of crabs in commercial size	–	0.26
	Mean crab size	0.11	0.12
Land use and cover	Mangrove vegetation types	0.02	0.03
	Distance of mangroves from fishery villages	0.06	0.18
	Distance of mangroves from shrimp farms	0.02	–
Social	Degrees of mangrove importance for crab conservation	0.02	0.05
	Degrees of mangrove use for crab fishery	0.06	0.07

Figure 3. Maps the biological criteria related to the population parameters of the crab *Ucides cordatus* in the mangroves of the São Francisco River Estuary (Northeast Brazil).

Figure 4. Maps the land use and cover criteria in the mangroves of the São Francisco River Estuary (Northeast Brazil).

Figure 5. Maps the social criteria related to the mangrove degree of importance for the conservation and fishery use of the crab *Ucides cordatus* in the mangroves of the São Francisco River Estuary (Northeast Brazil).

3.2 MCE analysis for the conservation and fishery of *Ucides cordatus* in the mangroves of the São Francisco River Estuary

MCE analysis help balance conflicting demands of environmental conservation and development with regards to coastal development and fishery allocation (Andalecio, 2010). In the present study the maps of the mangrove suitability for *U. cordatus* conservation (Figure 6) and fishery (Figure 7), generated by the MCE analysis, can help government agencies in the

delineation of fish exclusion and extractive areas, one of the aims stated in the Proposal of a National Management Plan for this species (Brasil, 2011).

For the conservation objective, the suitability map (Figure 6) shows that the mangrove areas more suitable for the conservation of the crab *Ucides cordatus* (classes: *extremely high*, *very high*, *high* and *moderately high*) are those more close to the São Francisco River mouth. On the other hand, the conservation suitability decreases as far as the mangrove areas are more distant from the estuary mouth (classes *medium*, *low* and *very low*) (Figure 6).

The classes more suitable for the crab conservation accounts together for more than 58% of the mangroves in the study area (Table 3) and show important characteristics for the conservation of *Ucides cordatus*, such as: high density and frequency of crabs in non-commercial size, small sized crabs, low degree of use for crab fishery, and they are more distant areas from the fishery villages and shrimp farming. In addition to these features, the class *extremely high* exhibits mangrove vegetation type 3 and 4 while the class *very high* showed mangrove vegetation types 1 and 2. For the crab conservation purpose, it is more adequate the mangrove forests with high green biomass, as found in mangrove vegetation types 3 and 4, and with the presence of *L. racemosa* besides to *R. mangle*, as found in mangrove type 4, which is correlated with the occurrence of small and juvenile crabs (Diele et al., 2005; Piou et al., 2009). The classes *high* and *moderately high* showed frequency of crabs in non-commercial size slightly lower than the classes *extremely high* and *very high*, and density of crabs in commercial size higher than these two last classes. However, the class *high* exhibited mangrove vegetation type 4, thus it is more suitable for the crab conservation than the class *moderately high*, and was the class with highest extent (Table 3).

The mangroves less suitable to the crab conservation (classes *medium*, *low* and *very low*) account for approximately 42% of their total area (Figure 6, Table 3), and are those more close to the fishery villages and shrimp farming, more used for the crab fishery by the local

populations, and showing high density of crabs in commercial size, big sized crabs, low frequency and density of crabs in non-commercial crabs. The presence or combination of these features make them not suitable as areas for the conservation of *Ucides cordatus*. For example, the class *medium* showed very proximity to fishery villages and shrimp farming, while the class *low* was that which recorded the highest density of commercial crabs and use. The class *very low* showed the largest crabs as well as the lowest density and frequency of crabs in non-commercial size.

For the fishery objective, the suitability map (Figure 7) shows that the mangrove areas more suitable for the fishery of the crab *Ucides cordatus* (classes: *extremely high*, *very high*, *high* and *moderately high*) are those located more far from to the São Francisco River mouth, mainly along the Poço and Carapitanga channels (Figure 7). The classes more suitable for the crab conservation accounts together for more than 59% of the mangroves in the study area (Table 4) and show important characteristics for the fishery of *Ucides cordatus* such as: high density and frequency of crabs in commercial size, low density of crabs in non-commercial size, big sized crabs, medium to high degree of use for crab fishery, mangrove vegetation type 3 and they are more close to the fishery villages. The class *extremely high* exhibits higher values of density of crabs in commercial size than the class *very high*, which showed the biggest crabs and the highest frequency of crabs in commercial size. For the crab fishery purpose, higher density of crabs in commercial size is more important than the mean crab size, as found by the AHP analysis (Table 2) since it produce large stocks of crabs for exploitation, representing the amount of crabs per square meters of mangrove which are in the legal capture size. The class most suitable (*extremely high*) for the fishery of *U. cordatus* occupies the highest extent in the study area (Table 4), thus showing the potential of these mangroves for the crab fishery.

In Brazil, two laws address the management of the *U. cordatus* fishery, one for the south-southeastern resource and the other for the north-northeastern resource (IBAMA, 2003a, 2003b). Both laws establish a minimum size (60 mm carapace width, CW), the protection of ovigerous females and the closure of the fishery during the reproductive season (Duarte et al., 2014). The establishment of a minimum size of capture is an important rule for the maintenance of the crab stock (Diele et al., 2005). Thus, mangrove areas with high density and frequency of crabs in the commercial size ($CW \geq 60$ mm) show high potential for a sustainable fishery.

The fishery suitable classes *high* and *moderately high* are more located along the mangroves of the Jibóia Island and in the backward part of the Oyster stream, respectively (Figure 7). These classes are those mangroves more close to the fishery villages, in addition to show a higher density of crabs in commercial size, mainly found in the Oyster stream. These highlights the importance of the weights (Table 2) given to these two criteria for the delineation of the mangrove areas mores suitable for the resource exploitation.

The areas less suitable to the crab fishery (classes *medium*, *low* and *very low*) account for roughly 40% of the total mangrove extent (Figure 7, Table 4) are those more distant from the fishery villages, less used for the crab fishery by the local populations, and showing high density and frequency of crabs in non-commercial size, small sized crabs, and mangrove vegetation types 1, 2 and 4. The presence or combination of these features make them not suitable for the fishery of *Ucides cordatus*, but to other objectives, as for the crab conservation (Figure 6).

In summary, the most suitable mangrove areas for the conservation of *U. cordatus* are those located close to the river estuary, mainly along the Parapuca channel and the Dema stream (classes *extremely high*, *very high*, Figure 6), accounting together 9.4 km² (Table 3). On the other hand, the areas most suitable for the crab fishery are those farm from the estuary

mouth and more close to the fishery villages, especially in the Carapitanga channel and Mosquito and Aracaré streams (classes *extremely high*, *very high*, Figure 7), accounting together 10.2 km² (Table 3). It is interest to note that the mangroves located along the of Oyster stream were classified by the two MCE analyses as suitable for fishery and conservation of the crab *U. cordatus* (classes *high* and *moderately high*, Figure 6 and 7). This is because these mangroves show characteristics that are important for both purposes. For example, high density of crabs in commercial size and mangrove vegetation type 3 are important features for the crab fishery, while high density of crabs in non-commercial size and mangrove vegetation type 4 are important for the crab conservation.

The high biomass and abundance of *U. cordatus* and the large extension of its habitat makes this semi-terrestrial crab a resource with a high fishery potential (Diele et al., 2005). The crab stocks and therefore their capture rates and yield reflect the extent and degree of development of mangroves (Brazil, 2011). This show the importance of the mangrove habitats for the maintenance of the fishery potential of this species. In the study area the high extent of mangrove areas (32 km²) with high developed stands (Santos et al., 2014), combined with the population structure of *U. cordatus*, and social and land use/cover features, characterize larges areas of these mangroves with high potential to the crab fishery. According to Diele et al. (2005), the potential yield of *U. cordatus* is comparable to or exceeds other important crab fisheries world-wide (e.g. USA 2001: 68 509 t hard blue crabs, 16 525 dungeness crabs, 11 246 t snow crabs; O'Bannon; Chesapeake Bay 1995: 33 500 t blue crabs, Rugolo et al. 1998; Europe 2001: 84 419 t crabs and sea-spiders; FAOstatdata 2004).

Figure 6. Map of land use and cover and mangrove suitability for the conservation of the crab *Ucides cordatus*, in the São Francisco River Estuary (Northeastern Brazil).

Figure 7. Map of land use and cover and mangrove suitability for the fishery of the crab *Ucides cordatus*, in the São Francisco River Estuary (Northeastern Brazil).

Table 3. Area (km²) of the classes of mangrove suitability for the conservation of the crab *Ucides cordatus*.

Suitability for the crab conservation	Classes of mangrove suitability for the crab conservation	Area (km ²)	Percentage (%)
More Suitable	Extremely high	5.1	16.0
	Very high	4.3	13.5
	High	6.2	19.4
	Moderately high	3	9.4
	Sub-total	18.6	58.3
Less Suitable	Medium	2.7	8.5
	Low	5.6	17.6
	Very low	5	15.7
	Sub-total	13.3	41.7

Table 4. Area (km²) of the classes of mangrove suitability for the fishery of the crab *Ucides cordatus*.

Suitability for the crab fishery	Classes of mangrove suitability for the crab fishery	Area (km ²)	Percentage (%)
More Suitable	Extremely high	5.7	17.9
	Very high	4.5	14.1
	High	4.4	13.8
	Moderately high	4.3	13.4
	Sub-total	18.9	59.2
Less Suitable	Medium	4.5	14.1
	Low	4.6	14.4
	Very low	3.9	12.3
	Sub-total	13	40.8

4. Conclusions

We concluded that the mangroves of the São Francisco River Estuary shows spatially different areas with high potential for the conservation and fishery of the crab *Ucides cordatus*. The combination of high potential for both objectives allow the implementation of management strategies in order to achieve a sustainable fishery of this resource, as stated by the Proposal of a National Management Plan for this species.

Based on the objectives of this proposal, the mangroves more suitable for the conservation of *U. cordatus* might be delineated as fish exclusion areas, since they show large abundance of small non-commercial crabs and are the less used for fishery. In the fish exclusion areas the crab fishery should be restrictive or not allowed, in order to permit the non-commercial size crabs grow to reach the commercial size, as well as, for their reproduction and maintenance of the resource stock in the study area. Similarly, the mangrove areas more suitable for the crab fishery can be delineated as extractive areas, since they show large abundance of commercial size and big crabs, and area close to the fishery villages.

In the MCE analysis the biological criteria related to the *U. cordatus* population structure, mainly density and frequency of crabs in non-commercial and commercial sizes, were more important than land use and cover and social criteria, for the delineation of the more suitable mangrove areas for the crab conservation and fishery, respectively. The combination of remote sensing and geoprocessing techniques and field surveys in a MCE showed to be an useful tool for fishery management purposes, since it allow the integration of different data, from social, biological and geographical sciences, thus being essential for the analysis, resource management and conservation of socio ecological complex systems, such as fishery in coastal and marine ecosystems.

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CAPÍTULO 6

Discussão Geral e Conclusões

CAPÍTULO 6

Discussão Geral e Conclusões

1. Contribuições locais

No presente estudo foi evidenciado que a pesca em áreas de manguezal é a principal atividade que sustenta a economia de subsistência das comunidades costeiras do estuário do Rio São Francisco. Essas comunidades exploram uma grande diversidade de recursos pesqueiros dos manguezais, incluindo 12 diferentes tipos de peixes, 4 espécies de caranguejos e 3 de moluscos. Dentre estes recursos, os peixes e caranguejos são os mais rentáveis economicamente, sendo o caranguejo *Ucides cordatus* o mais importante em três dos oito povoados pesqueiros que ocorrem na região. A elevada dependência econômica dessas populações sobre os recursos pesqueiros dos manguezais, ocorrendo a exploração dos recursos desde crianças ou jovens, conduziu a um desenvolvimento de um elevado conhecimento local sobre os mesmos, bem como sobre mudanças e impactos que veem afetando os estoques da pesca. Essa levada relação homem-manguezal tem sido evidenciada por vários autores em manguezais do Brasil (e.g. Nishida et al. 2004, Souto, 2008; Ferreira et al., 2009; Souto e Martins, 2009; Firmo et al., 2012; Magalhães et al., 2012, Cortês et al., 2014) e do mundo (e.g. Walters, 2003; Dahdouh-Guebas et al., 2006; Walters et al., 2008; Satyanarayana et al., 201, 2013).

Foi reconhecida, pelas comunidades locais do estuário do Rio São Francisco, uma elevada queda da produção dos peixes em geral e do caranguejo *Ucides cordatus* durante os últimos 13 anos. Essa informação é corroborada por dados estatísticos de desembarque pesqueiro, especialmente para *U. cordatus* (e.g. CEPENE, 1999, 2000,

2001, 2002, 2003, 2008). As principais causas apontadas pelos locais para essa queda de produção é o grande número de pescadores, devido a carência de empregos e alternativas de fonte de renda e a introdução e funcionamento de atividades de carcinocultura. Esses fatores foram indicados como os principais responsáveis pela drástica queda e mortandade do caranguejo *U. cordatus*, principalmente a carcinocultura por causar desflorestamento de vastas áreas de manguezais, removendo o habitat do caranguejo, e liberar efluentes letais à espécie diretamente nas águas do manguezal. Essa elevada mortandade também foi observada em outros locais da costa brasileira (e.g. Boeger et al., 2005; Schmidt, 2006; Firmo et al., 2011), e alguns artigos tem indicado como causa um fungo, que estaria causando a Doença do Caranguejo Letárgico (DCL) (e.g. Boeger et al., 2005; 2007). É interessante ressaltar que embora tenha se constatado um elevado conhecimento local acerca de aspectos biológicos, ecológicos e conservacionistas do *U. cordatus* pelos pescadores do estuário do Rio São Francisco, nenhuma referência foi feita à doença do caranguejo letárgico, ou a qualquer outro tipo de doença.

A estrutura populacional do caranguejo *U. cordatus* nos manguezais da área de estudo revelou que esta região apresenta um elevado potencial pesqueiro para esta espécie, com grande abundância (frequência e densidade) de caranguejos em tamanho comercial, notavelmente e estatisticamente maior que a abundância de caranguejos em tamanho não comercial. Entretanto, baixos valores de densidade média, ao se comparar com os valores registrados em outros manguezais na costa Norte, Nordeste e Sudeste/Sul do Brasil, pode constituir um fator limitante para a pesca. Essa baixa densidade pode ser reflexo da elevada mortandade ocorrida na área de estudo em 2000, com recomposição da população a partir de 2010, que foi apontada pelos pescadores locais e evidenciada nos dados estatísticos de desembarque (e.g CEPENE, 2008). A

mesma evidência de baixa densidade caranguejo relacionada à mortalidade do caranguejo também foi observada por Alves e Nishida (2004) em manguezais do estuário do Rio Mamanguape (Nordeste do Brasil). Brasil (2001) também indica que a mortalidade em massa de *U. cordatus* teve grande impacto socioeconômico, com expressiva redução da densidade dos caranguejos com tamanho comercial.

A importância econômica e social da pesca do caranguejo e o atual cenário de pressões antrópicas geradas pela carcinocultura, a queda na produção desse recurso, aliados à elevada mortalidade, o status populacional com baixos valores de densidade dessa espécie nos manguezais do estuário do Rio São Francisco, e elevada pressão pesqueira sobre esse recurso revelam a necessidade de implementação de medidas de manejo da pesca, que permita o uso sustentável do recurso e sua conservação e manutenção/recuperação do estoque.

A gestão do uso sustentável dos recursos pesqueiros no Brasil tem, historicamente, sido fundamentada na adoção de medidas que são agrupadas em dois conjuntos principais (Dias-Neto, 2003; Marrul-Filho, 2003): proteção de parte selecionada dos estoques e limitação de tamanho das capturas (Brasil, 2011). A proteção de parte selecionada dos estoques é um conjunto de medidas que visa possibilitar a existência de um potencial reprodutivo capaz de permitir um adequado recrutamento, e que impossibilite a captura de indivíduos em fases críticas dos seus ciclos de vida (Brasil, 2011). Para a proteção de parte selecionada dos estoques, são utilizadas as seguintes medidas: suspensão da pesca durante certos períodos (defeso); fechamento de áreas de pesca; proteção de reprodutores; limite de comprimento e peso (tamanho mínimo de captura); restrição sobre aparelhos de pesca (Brasil, 2011). Para a pesca do caranguejo *U. cordatus* no Brasil parte dessas medidas já são implementadas por leis (e.g. IBAMA, 2003a, 2003b), que estabelecem um tamanho mínimo de captura

(largura da carapaça maior ou igual à 60 mm), proibição da pesca de fêmeas ovígeras, proibição da pesca durante a estação reprodutiva (defeso) e a permissão de métodos de pescas não predatórios, como o braceamento (IBAMA, 2003a, 2003b, Duarte et al., 2014).

Mais recentemente foi publicada a Proposta de Plano Nacional de Gestão para o Uso Sustentável do Caranguejo-Uçá (*Ucides cordatus*), do guaiamum (*Cardisoma guanhumi*) e do siri-azul (*Callinectes sapidus*) (Brasil, 2011). Esse plano visa contribuir com a manutenção/recuperação dos estoques naturais dessas espécies e de seus habitats por todo o território nacional, numa visão de curto, médio e longo prazos, com vistas ao seu uso sustentável, segundo aspectos biológico-pesqueiros, ecológicos, sociais, econômicos e legais (Pinheiro e Rodrigues, 2011). Para o caranguejo *U. cordatus* é referida a definição de Áreas Extrativas (AEs) e Áreas de Exclusão de Pesca (AEPs) como objetivo específico referente aos aspectos biológico-pesqueiros. De acordo com esse plano, a definição das melhores AEs e AEPs nos sistemas estuarino-lagunares brasileiros, deve ser realizada com uso de técnicas de geoprocessamento e informações já disponíveis para a espécie em questão (Brasil, 2011).

No presente estudo, por meio de uma análise multicritério realizada em ambiente de geoprocessamento, foram gerados mapas da aptidão dos manguezais para a pesca e conservação do caranguejo *U. cordatus* nos manguezais do estuário do Rio São Francisco. A vantagem de se utilizar essa análise é que foi possível a integração de dados de diferentes campos, tais como biológicos relativos à estrutura populacional do caranguejo, dados sobre o arranjo espacial da paisagem e uso e cobertura do solo, tais como tipos vegetacionais de bosques de mangue, distância dos manguezais em relação aos povoados pesqueiros e empreendimentos de carcinoculturas, e dados sociais, referentes ao uso dos manguezais para a atividade pesqueira do caranguejo e percepção

local acerca das áreas de mangue mais importantes para a conservação dessa espécie. Ao se estudar sistemas sócio-ecológicos complexos essa abordagem é fundamental pois permite considerar os vários e diferentes fatores que incidem no sistema complexo em consideração.

Os manguezais com maior aptidão para a conservação do caranguejo representam 29.5% dos manguezais da área de estudo são aqueles localizados próximos à foz do estuário e apresentam importantes características para a conservação e manutenção do estoque da espécie, tais como: alta densidade e frequência de caranguejos em tamanho não comercial, caranguejos pequeno e juvenis, baixo grau de utilização para pesca, e são as áreas mais distantes dos povoados pesqueiros e dos empreendimentos de carcinocultura. Já os manguezais mais aptos para a pesca do caranguejo representam 32% da área de mangue total e estão localizados distantes da foz e exibem alta densidade e frequência de caranguejos de tamanho comercial, baixo densidade de caranguejos em tamanho não comercial, caranguejos de elevado tamanho, médio a alto grau de uso para pesca, elevada proximidade aos povoados pesqueiros, vegetação de mangue com elevada biomassa verde e dominância da espécie *Rhizophora mangle*. Áreas de manguezal com predomínio de *R. mangle* são as mais indicadas para a exploração racional desse recurso, pois embora apresentem menor densidade geral, detêm os maiores tamanhos médios de indivíduos e percentuais de potencial extrativo imediato (Brasil, 2011).

A presença de manguezais com alto potencial para ambos os objetivos, ou seja, para a pesca e conservação de *U. cordatus*, permite a implementação de estratégias de manejo e conservação indicadas na Proposta do Plano Nacional de Gestão para o Uso Sustentável do Caranguejo-Uçá. Com base nos objetivos biológico-pesqueiros desse plano e nos resultados do presente estudo, os manguezais mais aptos para a conservação

de *U. cordatus* podem ser delineados como áreas de exclusão de pesca. Nas áreas de exclusão a pesca do caranguejo deve ser restritiva ou não permitida, visando permitir que os caranguejos de tamanho não comercial cresçam até atingirem o tamanho comercial, bem como, reprodução e manutenção do estoque. Similarmente, as áreas de mangue mais aptas para a pesca do caranguejo pode ser delineada como áreas extrativistas.

Na atualidade, é reconhecida a necessidade de se avançar e complementar o manejo de pesca, incorporando medidas que adotem, sempre que possível, a visão ecossistêmica e a criação de unidades de conservação, especialmente protegidas, no processo de gestão do uso sustentável dos recursos pesqueiros no Brasil (Brasil, 2011).

Portanto, além das medidas de manejo da pesca referidas acima, vale resaltar que a implementação de outras medidas de gestão local toram-se necessárias para uma redução da pressão da pesca, por meio da geração de alternativas de fonte de renda e emprego, que possibilitem a melhoria da qualidade de vida das populações locais, de forma sustentável, como apontado no decreto n.º 22.995 de 09 de novembro de 2004, que criou a Área de Proteção Ambiental (APA) Litoral Norte (Sergipe, 2004), na qual a área de estudo está incluída. As alternativas mais apontadas pelas populações locais para o desenvolvimento local e melhoria da qualidade de vida foram: criação de uma indústria de pequena escala para o beneficiamento dos pescados, suporte do governo para cultivar ostras e peixes nativos de forma sustentável e "amiga do manguezal" (*mangrove-friendly aquaculture practices*, e.g. Primavera, 2006) e para adquirir barcos motorizados, desenvolvimento do eco-turismo e criação de uma unidade de conservação de uso sustentável da categoria "Reserva de Desenvolvimento Sustentável", a qual se encaixa nas características apresentadas pela área de estudo. Todas essas atividades são boas alternativas sócio-ecológicas para a redução da pobreza

e melhoria da qualidade de vida, diminuição da pressão pesqueira e uso sustentável dos recursos dos manguezais e devem ser consideradas para a sustentabilidade local.

2. Contribuições Nacional e mundial

É inquestionável o papel dos manguezais como fornecedores de bens e serviços para as populações humanas ao longo das zonas costeiras tropicais e subtropicais do mundo (e.g. Schaeffer-Novelli, 1991; Rönnbäck, 1999; Barbier, 2000; FAO, 2007; Walters et al., 2008, Spalding et al., 2010; Barbier et al. 2013). No presente estudo foram evidenciadas funções sócio-ecológicas desempenhadas pelos manguezais tais como: habitat para diversas espécies pesqueiras, fornecedor da base das pescarias artesanais, fonte de subsistência, alimento e renda econômica para populações humanas, patrimônio de conhecimento local e tradicional sendo importante para a construção da identidade cultural das populações humanas costeiras. Essas funções ressaltam a importância de se conservar os manguezais frente aos diferentes impactos que veem reduzindo a área e a qualidade ambiental do ecossistema, bem como de se considerar medidas de manejo e gestão da pesca, de forma a se alcançar a sustentabilidade sócio-ecológica e econômica das zonas costeiras tropicais e subtropicais do mundo.

A zona costeira do Brasil apresenta vastas áreas de manguezais nos quais o caranguejo *U. cordatus* é amplamente explorado e apresenta grande valor socio-econômico, apesar de vários fatores como doenças, destruição dos manguezais e pressão de pesca estarem prejudicando os estoques desse recurso. Por meio da Instrução Normativa nº 5, de 21 de maio de 2004 do Ministério do Meio Ambiente, o caranguejo *U. cordatus* está incluído na Lista Nacional das espécies de invertebrados aquáticos e peixes sobreexploradas ou ameaçadas de sobreexploração. Essa mesma normativa define que o IBAMA deve elaborar para as espécies dessa lista, planos de gestão para o uso

sustentável, sendo assim elaborada a Proposta de Plano Nacional de Gestão para o Uso Sustentável do Caranguejo-Uçá (Brasil, 2011).

Considerando esse cenário, o presente estudo apresenta uma base metodológica, com a integração de diferentes dados em uma análise multicritério, para o mapeamento da aptidão de manguezais para a conservação e pesca do *U. cordatus* em outras regiões do Brasil, que apresentam alta exploração e risco de esgotamento desse recurso, corroborando para o alcance dos objetivos biológico-pesqueiros propostos nesse plano. A metodologia aqui aplicada pode ser utilizada pelos órgãos gestores ambientais e da pesca para o cumprimento desses objetivos.

Enquanto análises multicritério veem aumentando cada vez mais para tomadas de decisão e gestão de recursos naturais, sua aplicação para a gestão e manejo da pesca ainda vem sendo lenta, apesar de ser reconhecida sua relevância (Andalecio, 2010). O presente estudo resalta a importância da análise multicritério para o manejo e conservação de espécies pesqueiras, principalmente ao se considerar a pesca como um sistema socio-ecológico complexo, permitindo a agregação e análise de diferentes variáveis. A aplicação de análise multicritério e da abordagem sócio-ecológica não se restringe apenas para a pesca em manguezais do Brasil, mas sim para os demais países que apresentam exploração e utilização de diferentes recursos naturais desse ecossistema. Os recursos dos manguezais veem sendo tradicionalmente utilizados na maioria dos países em que existem (FAO, 2003). Uma grande variedade de produtos florestais são extraídos dos manguezais, especialmente madeira para combustível e construção, taninos e medicamentos, bem como de uma diversidade de recursos pesqueiros (Rönnbäck et al., 199; Waters et al., 2008). Para muitas comunidades costeiras, o uso tradicional de recursos dos manguezais está intimamente ligado com a

saúde e funcionamento do sistema, e, portanto, esta utilização é ligada à cultura local, herança e conhecimento tradicional (Walters et al., 2008).

Com base nos resultados do presente estudo e de outros autores (e.g. Cortês et al., Duarte et al., 2014), o conhecimento local dos pescadores do estuário do Rio São Francisco acerca da biologia e ecologia do caranguejo *U. cordatus* e principalmente a aplicação de práticas conservacionistas na utilização da redinha, sugere uma revisão da portaria do IBAMA (IBAMA, 2003a, 2003b), que proíbe o uso desse petrecho de pesca. Essa mesma revisão também foi sugerida por Duarte et al. (2014) que concluiu que a utilização da redinha resulta em níveis similares de produtividade obtida por meio de outros métodos permitidos legalmente. Esses autores também recomendam que um tipo de armadilha semelhante à redinha mas constituído de material biodegradável deva ser desenvolvido, de forma a evitar a poluição por fios de nylon nos manguezais. Vale ressaltar que a redinha é mais segura e preserva a saúde física dos coletores, o que é importante para os pescadores com dependência econômica de longo prazo na pesca do caranguejo (Cortês et al., 2014), como constatado através de entrevistas com os pescadores da área de estudo. O envolvimento dos extrativistas nas discussões é uma ação que ajuda no ordenamento da atividade e preservação do recurso, visto que o conhecimento etnobiológico dos catadores contribui para o maior conhecimento da pesca (Fiscarelli e Pinheiro, 2002), somando com o saber técnico-científico visando uma regulamentação da captura de forma dinâmica e efetiva (Jankowsky, 2007, Mendonça e Pereira, 2009) e sustentável socialmente.

Considerando esse contexto, a abordagem sócio-ecológica é de extrema importância para a conservação, gestão e manejo dos manguezais e dos recursos explorados. Muitos planos de conservação permanecem não implementado, em parte devido à insuficiente consideração dos processos sociais que influenciam as decisões de

conservação e manejo (Ban et al., 2013). Portanto, a inclusão do planejamento da conservação no arcabouço teórico de sistema social-ecológico (SES) complexo (e.g. Ostrom, 2009) pode levar a uma compreensão mais completa das interações homem-ambiente e integração mais eficaz dos aspectos sociais (Ban et al., 2013).

3. Conclusões

- Os recursos pesqueiros dos manguezais do estuário do Rio São Francisco constituem a principal base da economia de subsistência das populações humanas que habitam essa região. Esses recursos são explorados tradicionalmente por essas comunidades que detêm um elevado conhecimento ecológico, biológico e conservacionista, demandando assim, planos e estratégias de gestão que visem a conservação das florestas de manguezal, o uso sustentável desses recursos e a melhoria da qualidade de vida da população local.

- Dentre a diversidade de recursos pesqueiros explorados, o caranguejo *Ucides cordatus* é um dos produtos mais importantes economicamente. Uma forte dependência econômica nesse recurso, ocasionada por uma carência de empregos e alternativas de renda, conduziu a um elevado etnoconhecimento sobre o tamanho populacional e corporal, ciclo de vida, diferenciação sexual, comportamento, habitat e causas de elevada mortalidade do *Ucides cordatus* nos manguezais do estuário do Rio São Francisco. Esse conhecimento pode auxiliar na implementação de medidas de manejo da pesca desse recurso no local, como a definição dos períodos de defeso, bem como indica a necessidade de revisão da portaria IBAMA Nº 034/03-N (IBAMA, 2003), que proíbe o método de captura pela redinha.

- A composição da vegetação de manguezal possui forte influência na estrutura da população *U. cordatus*, com ocorrência dos caranguejos de maiores tamanhos em

bosques de mangue dominados pela espécie típica *Rhizophora mangle*. A presença da espécie *Laguncularia racemosa* e *Acrostichum aureum* está ligada à ocorrência de caranguejos de menores tamanhos. Assim como apontado por outros autores, o presente estudo também levanta a hipótese de que o principal fator que causa este padrão é a competição intra-específica, na qual os caranguejos maiores excluem os menores do habitat de preferência, que são os bosques de *R. mangle*.

- A estrutura populacional do caranguejo *U. cordatus* nos manguezais do Rio São Francisco revelou que embora haja uma elevada abundância (densidade e frequência) de caranguejos em tamanho comercial do que os de tamanho não comercial, a densidade média registrada nesses manguezais foi em geral mais baixa que as registradas em outras áreas de manguezais do Brasil. O presente estudo argumenta que essa menor densidade é causada principalmente por uma alta taxa de mortalidade do caranguejo que ocorreu em 2000, o desmatamento dos manguezais para a introdução de empreendimentos de carcinocultura e também devido à uma alta pressão de pesca sobre esse recurso.

- Os manguezais do Estuário do Rio São Francisco apresentam alto potencial tanto para a pesca bem como para a conservação do caranguejo *U. cordatus*, o que permite a integração de medidas de manejo para uma pesca sustentável. Os manguezais mais aptos para a conservação do caranguejo estão localizados próximos à foz do estuário enquanto que aqueles com maior aptidão para a pesca estão localizados distantes da foz e próximos aos povoados pesqueiros. Esses manguezais apresentam, principalmente, distintas características da estrutura da população do caranguejo, diferentes tipos vegetacionais de bosques de mangues e diferentes graus de uso e distância em relação aos povoados pesqueiros.

- A análise multicritério desenvolvida em ambiente de geoprocessamento, considerado diferentes fatores sociais, biológicos e de uso do *U. cordatus*, bem como da paisagem na qual está inserido, constitui importante ferramenta para a definição de áreas de extrativismo e de exclusão de pesca desse recurso, fornecendo subsídios metodológicos para o cumprimento dos objetivos do Plano Nacional de Gestão para o Uso Sustentável do Caranguejo-uçá.

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RESUMO

No Nordeste do Brasil, o estuário do Rio São Francisco apresenta extensas áreas de manguezais (32 km²) cujos recursos são utilizados por populações humanas. Este estudo considerou a metodologia de sistemas sócio-ecológicos complexos para analisar a pesca nos manguezais desse estuário, com ênfase no caranguejo *Ucides cordatus*. Por meio da integração de dados de diferentes áreas (etnobiologia, levantamentos socioeconômicos, estrutura populacional do caranguejo, características da vegetação, arranjo espacial da paisagem, sensoriamento remoto e geoprocessamento) em uma análise multicritério, foi determinada e mapeada a aptidão dos manguezais para a conservação e a pesca dessa espécie. Uma diversidade de recursos pesqueiros do manguezal (por exemplo, peixes, caranguejos e moluscos), constitui a principal base da economia de subsistência local, em que o caranguejo *U. cordatus* é o mais importante. As populações locais possuem um vasto conhecimento sobre o tamanho populacional e corporal, ciclo de vida, diferenciação sexual e habitat dessa espécie, e aplicam práticas conservacionistas no uso da redinha. A estrutura populacional do caranguejo revelou um alto potencial pesqueiro, com maior abundância de caranguejos de tamanho comercial do que os de tamanho não comercial. Os manguezais mais aptos para a conservação de *U. cordatus* (9,4 km²) estão localizados próximos à foz e apresentam alta abundância de caranguejos não comerciais, baixa densidade de caranguejos comerciais e baixo grau de utilização para a pesca. Os manguezais mais aptos para a pesca (10,2 km²) estão distantes da foz e apresentam alta abundância de caranguejos de tamanho comercial, baixa densidade de caranguejos em tamanho não comercial, caranguejos grandes, médio a alto grau de uso e estão próximos aos povoados. Os mapas de aptidão gerados podem auxiliar as agências governamentais no delineamento de áreas extrativistas e de exclusão da pesca, como sugerido no Plano Nacional de Gestão para o Uso Sustentável do Caranguejo-uçá.

ABSTRACT

In Northeastern Brazil, the São Francisco River Estuary comprises a significant mangrove area (32 km²) used by local human populations. This study considered the framework of socio-ecological systems to analyze the mangrove fishery in this estuary, with emphasis on the crab *Ucides cordatus*. By the integration of data from different fields (ethnobiology and socio-economic surveys, crab population structure, vegetation features, landscape arrangement, remote sensing and geoprocessing) in a multi-criteria analysis, we determined and mapped the suitability of the mangroves for the conservation and fishery of this species. We found that a diversity of mangrove fisheries (e.g. fish, crabs and mollusks) constitute the main base of the local subsistence economy, wherein the *Ucides cordatus* is the most important. The local populations have a substantial knowledge about this crab population and body sizes, life cycle, sexual differentiation, behavior and habitat, and apply conservation practices in the use of the "redinha". The population structure of the crab *U. cordatus* revealed a high fishery potential, with higher abundance (frequency and density) of crabs in commercial size than the non-commercial sized crabs. The mangroves more suitable for the crab conservation (9.4 km²) are those close to the river mouth, showing high abundance of non-commercial crabs, low density of commercial crabs and low degree of use for fishery. On the other hand, the mangroves more suitable for the crab fishery (10.2 km²) are those located far from to river mouth, showing high density and frequency of crabs in commercial size, low density of crabs in non-commercial size, big sized crabs, medium to high degree of use, and are close to the fishery villages. The maps of suitability can aid government agencies in delineating extractive and fishery exclusion areas, as stated by the Proposal of a National Management Plan for this crab, in order to achieve a sustainable fishery.