UNIVERSIDADE FEDERAL DO PARÁ

INSTITUTO DE ESTUDOS COSTEIROS

CAMPUS UNIVERSITÁRIO DE BRAGANÇA

PROGRAMA DE PÓS-GRADUAÇÃO EM BIOLOGIA AMBIENTAL

Ostreicultura no Nordeste Paraense: estado atual e perspectivas futuras.

DIONISO DE SOUZA SAMPAIO

Prof. Dr. Colin Robert Beasley - **Orientador**

(IECOS/UFPA – *Campus* de Bragança)

Bragança – PA

2017

DIONISO DE SOUZA SAMPAIO

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Tese de Doutorado apresentada ao Programa de Pós-Graduação em Biologia Ambiental da Universidade Federal do Pará (UFPA) - Bragança, Instituto de Estudos Costeiros (IECOS), como requisito final para obtenção do título de Doutor em Biologia Ambiental (Área de concentração: Recursos Biológicos da Zona Costeira Amazônica).

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2017

Dioniso de Souza Sampaio

Tese apresentada para obtenção do grau de Doutor em Biologia Ambiental, ao Programa de Pós-Graduação em Biologia Ambiental: Recursos Biológicos da Zona Costeira Amazônica, da Universidade Federal do Pará.

Data de aprovação – Bragança/PA: 14/07/2017

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BIOLOGIA AMBIENTAL PÓS-GRADUAÇÃO

IECOS Instituto de Estudos Costeiros
Universidade Federal do Pará – Campus de Bragança

ATA DA DEFESA DE TESE DE DOUTORADO DO PROGRAMA DE PÓS-GRADUAÇÃO EM BIOLOGIA AMBIENTAL APRESENTADA E DEFENDIDA PELO DOUTORANDO DIONISO DE SOUZA SAMPAIO

Aos quatorze dias do mês de julho do ano dois mil e dezessete (14/07/2017), as 14:00h, na sala de Videoconferência, Campus Universitário de Bragança – PA, a Comissão Examinadora da Defesa de tese de Doutorado, designada pelo Colegiado do Programa de Pós-Graduação em Biologia Ambiental, reuniu-se em sessão ordinária para julgar a apresentação e defesa do doutorando **DIONISO DE SOUZA SAMPAIO,** intitulada: **OSTREICULTURA NO NORDESTE PARAENSE: ESTADO ATUAL E PERSPECTIVAS FUTURAS**. A Comissão Examinadora, obedecendo ao disposto nas Resoluções do Conselho Superior de Ensino e Pós-Graduação da Universidade Federal do Pará, foi constituída pelo Prof. Dr. Colin Robert Beasley – Presidente, (sem direito a voto); pelos membros: Profa. Dra. Nelane do Socorro Marques da Silva – Membro Titular; Profa. Dra. Maria de Lourdes Souza Santos – Membro Titular; Profa. Dra. Iracely Rodrigues da Silva – Membro Titular; Prof. Dr. Cleidson Paiva Gomes – Membro Titular e; Profa. Dra. Claudia Helena Tagliaro – Membro Suplente. Após haver o candidato apresentado a sua TESE DE DOUTORADO, obedecendo ao prazo regimental, foi dada a palavra aos examinadores para argüição, tendo o candidato respondido adequadamente às perguntas formuladas. Logo após, reuniu-se a Comissão Examinadora para proceder ao julgamento, sendo atribuídas as seguintes notas: Profa. Dra. Nelane do Socorro Marques da Silva, nota:.....10..........; Profa. Dra. Maria de Lourdes Souza Santos, nota.....10............; Profa. Dra. Iracely Rodrigues da Silva, nota.........10.......... e Prof. Dr. Cleidson Paiva Gomes, nota:.........9,8...... Assim sendo, a Comissão Examinadora decidiu aprovar o candidato com o conceito...EXCELENTE..., considerando-o Doutor em Biologia Ambiental, ênfase em Recursos Biológicos da Zona Costeira Amazônica. Nada mais havendo a tratar, o Presidente da Banca Examinadora deu por encerrado os trabalhos e foi lavrada a presente ata que vai devidamente assinada pelo presidente e examinadores.

Colin Beasley

Prof. Dr. Colin Robert Beasley

Nelane Marques

Profa. Dra. Nelane do Socorro Marques da Silva

Maria de Lourdes Souza Santos

Profa. Dra. Maria de Lourdes Souza Santos

IRSilva

Profa. Dra. Iracely Rodrigues da Silva

Prof. Dr. Cleidson Paiva Gomes

DEDICATÓRIA

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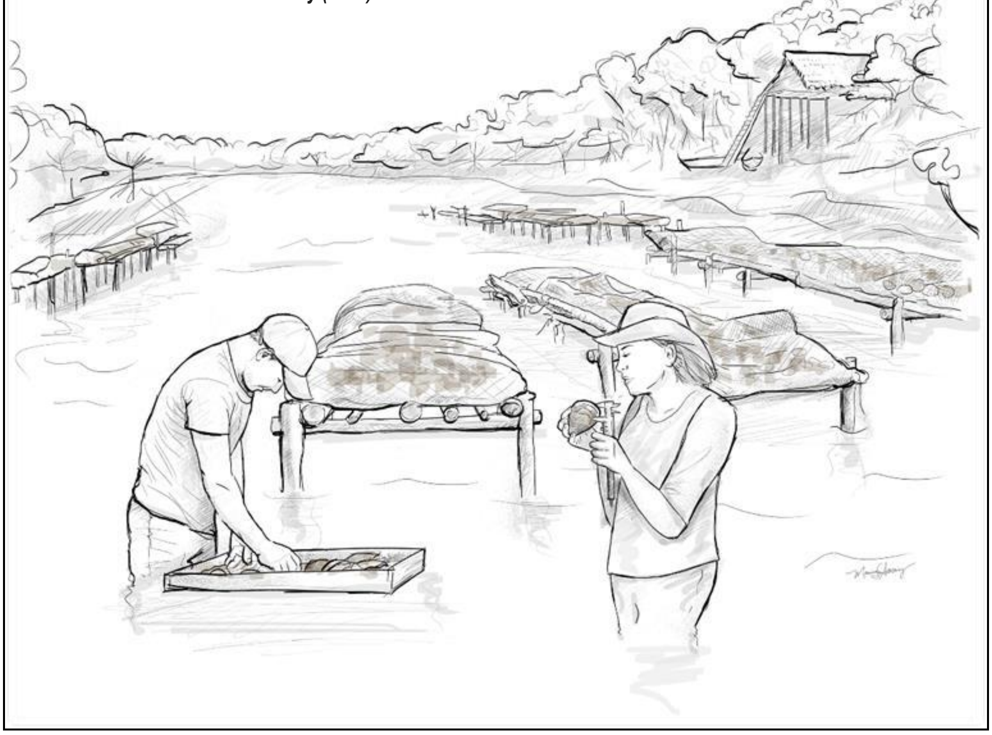

Dedico,

Aos meus pais Jackson Sampaio e Célia Sampaio,

A minha família, Sandra/Esposa; Pollyanna/Filha; João Pedro/Filho; Rodrigo/Genro,

Aos produtores de ostras do Estado do Pará.

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“Loucura não é cometer loucuras, e sim não conseguir escondê-las. Todos os homens erram, mas o sábio esconde os enganos que cometeu, enquanto o louco os torna públicos. A reputação depende mais do que se esconde do que daquilo que se mostra. Se você não pode ser bom, seja cuidadoso”.

Baltasar Gracián (1601-1658)

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"Doutorado é parto e parte é repartida com a vida (amigos e família)"

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RESUMO

No primeiro artigo (Capítulo 1), foram avaliados os aspectos relacionados à cadeia de suprimentos de ostra no estado do Pará. Entre 2013 e 2014, foram realizadas pesquisas em sete associações envolvidas na cultura da ostra através de entrevistas com o presidente de cada associação, bem como com 56 membros (72% do total). Dados secundários foram obtidos com a permissão de relatórios de gestão do Serviço Brasileiro de Apoio às Micro e Pequenas Empresas do Estado do Pará. As associações Agromar, Nova Olinda e Aquavila, Lauro Sodré destacam-se do resto devido às suas maiores áreas em crescimento e produção total em 2013. No entanto, as associações menores são mais eficientes com maior produção por unidade de área. Embora as associações tenham crescido em número desde 2006, juntamente com o aumento da capacidade e produção devido à assistência do governo, em comparação com outras regiões do Brasil, elas precisam ser melhor organizadas internamente. As associações devem ser menos dependentes do financiamento público e desenvolver mais parcerias com empresas privadas. Além disso, deve haver co-participação ativa no desenvolvimento de legislação e políticas públicas que regulam a cultura de ostra e a proteção de bancos naturais de ostras. No segundo artigo (Capítulo 2), o presente estudo investigou as características físico-químicas da água em todas as unidades de cultivo de ostra no Pará. A salinidade, a temperatura (^oC), o potencial de oxidação-redução (mV), o pH, o oxigênio dissolvido ($mg.l^{-1}$), a profundidade (m) e a concentração de clorofila-a ($mg.m^3$) foram medidos *in situ*, tanto na estação seca de 2013 como na estação chuvosa de 2014. Todas as variáveis, exceto a profundidade, foram significativamente maiores na estação seca. A salinidade média, que variou de 2,4 a 46, é a variável mais importante que explica a variação entre associações em relação à estação, data de amostragem em cada estação e estado da maré. No entanto, o oxigênio dissolvido, pH e profundidade também foram importantes.

As unidades de cultivo de ostra no Pará podem ser definidas em termos de qualidade da água como adequadas para a colheita de sementes da natureza (menor salinidade e pH), ou para o crescimento de adultos (maiores valores de salinidade, pH e profundidade). No terceiro artigo (Capítulo 3), o assentamento, o tamanho da semente, o desenvolvimento larval no laboratório, o crescimento e os aspectos da comercialização de ostras cultivadas foram investigados de 2012 a 2016 em cinco unidades de cultivo no Pará, durante períodos variando de 6 a 12 meses. O comprimento da semente diferiu entre dezembro de 2014 (21 mm) e abril de 2015 (12 mm) e menor tamanho aparece associado a uma maior precipitação. O número de sementes nativas foi maior na área em crescimento, enquanto a abundância de sementes exóticas foi baixa. O desenvolvimento larval é melhor em salinidades de 16 e 21, em que o estágio pediveliger apareceu após 53 dias. O crescimento de ostra em cultivo foi variável, mas o tamanho do mercado foi atingido em pelo menos 4 meses em Agromar, Aappns e Asapaq. A mortalidade variou de 19% a 46%, comparável a outras cultivos de *C. gasar*. A massa de ostra varia mensalmente e entre culturas, e está relacionada à seleção de tamanho pré-venda. Em média, ostras nas classes Baby e Médio são 77% e 80% de concha. Aquavila é adequado para a colheita de sementes, enquanto Agromar tem a menor mortalidade e é adequado para o crescimento. A maioria das ostras vendidas na Agromar está dentro dos limites da classe, enquanto aquelas vendidas na Aquavila são maiores.

Palavras-chave: *Crassostrea gasar*, Maricultura, Recursos Costeiros.

ABSTRACT

In the first article (Chapter 1), aspects related to the oyster culture supply chain in the state of Pará were evaluated. Between 2013 and 2014, research was carried out in seven associations involved in oyster culture through interviews with the president of each association, as well as with 56 members (72% of the total). Secondary data were obtained with the permission of management reports from the Brazilian Micro and Small Business Support Service of the State of Pará. The associations Agromar, Nova Olinda and Aquavila, Lauro Sodré stand out from the rest due to their larger on-growing areas and total production in 2013. However, smaller associations are more efficient with higher production per unit area. Although associations have grown in numbers since 2006, along with increased capacity and output due to government assistance, compared to other regions of Brazil, they need to be better organized internally. Associations should be less reliant on public funding and develop more partnerships with private enterprise. In addition, there must be active co-participation in the development of legislation and public policies that regulate oyster culture and the protection of natural oyster beds. In the second article (Chapter 2), the present study investigated the physico-chemical characteristics of water at all oyster farming units in Pará. Salinity, temperature (^{o}C), oxidation-reduction potential (mV), pH, dissolved oxygen (mg.l^{-1}), depth (m) and the concentration of chlorophyll-a (mg.m^{3}) were measured *in situ* in both the dry season of 2013 and the rainy season of 2014. All variables, except depth, were significantly higher in the dry season. Mean salinity, which ranged from 2.4 to 46, is the most important variable that explains the variation between associations in relation to the season, date of sampling in each season and state of the tide. However, dissolved oxygen, pH and depth were also important. Oyster culture units in Pará can be defined in terms of water quality as suitable for harvesting seed from the wild (lower salinity and pH), or for on-growing of adults (higher values of salinity, pH and depth). In the third article (Chapter 3), settlement, seed size, larval development in the laboratory, growth and aspects of the commercialization of cultivated oysters were investigated from 2012 to 2016 in five culture units in pará, during periods varying from 6 to 12 months. Seed length differed between December 2014 (21 mm) and April 2015 (12 mm) and smaller size appears associated with higher precipitation. Native seed numbers were higher in the on-growing area whereas abundance of exotic seed was low. Larval development is best at salinities of 16 and 21, in which the pediveliger stage appeared after 53 days. Oyster growth in culture was variable, but market size was reached in at least 4 months at Agromar, Aappns and Asapaq. Mortality ranged from 19% to 46%, comparable to other *C. gasar* cultures. Oyster mass varies monthly and between crops, and is related to pre-sale size selection. On average, oysters in the Baby and Médio classes are 77% and 80% shell. Aquavila is suitable for harvesting seed, whereas Agromar has the lowest mortality and is suitable for on-growing. Most of the oysters sold at Agromar are within the class limits, whereas those sold at Aquavila are larger.

Key words: *Crassostrea gasar*, Mariculture, Coastal Resources.

Introdução Geral

1) Introdução

1.1 Ostreicultura no Mundo, Brasil e no Pará

As ostras são moluscos bivalves cultivadas para consumo humano e colheita de pérolas. O cultivo de ostras é uma atividade que se caracteriza pelo baixo custo de implantação e manutenção e pelo rápido retorno do capital, tornando-se uma ótima opção de trabalho e renda para as populações tradicionais (Arana, 2003; Sampaio, *et al*., 2006).

No Brasil, são comercializadas três espécies de ostras, duas nativas, *Crassostrea rhizophorae* (Guilding, 1828), *Crassostrea gasar* (Adanson, 1757) que é sinônimo com *Crassostrea brasiliana* (Lamarck, 1819), e uma exótica, *Crassostrea gigas* (Thunberg, 1793) do Oceano Pacífico. Embora exótica, a *Crassostrea gigas* é a ostra mais cultivada no Brasil, devido ao investimento no cultivo desta espécie nos estados do sul, onde *Crassostrea gigas* se desenvolve melhor nas águas mais frias (BMLP, 2006; Ostrensky *et al*., 2008; Carranza *et al*., 2009; Barbieri *et al*., 2014).

Crassostrea gasar está presente em toda a costa brasileira e é a espécie cultivada no Estado do Pará (Varela *et al*. 2007, Melo *et al*. 2010a,b). A espécie nativa *C. rhizophorae* e a espécie exótica *Crassostrea sp*. (invasora) foram detectadas na costa do Pará (Gardunho et al, 2012). Galvão et al. (2012) sequenciando ostras do litoral de São Paulo, verificaram a presença das mesmas três espécies encontradas por Varela *et al*. (2007). Amostras com sequências de COI idênticas às encontradas para a espécie de *Crassostrea* sp. exótica do Pará e São Paulo foram descritas em uma população de ostras da China por Liu *et al*. (2011).

Estudos genéticos em populações de *Crassostrea virginica* na costa Atlântica e no Golfo do México, nos Estados Unidos, mostraram clara diferenciação entre populações da costa Atlântica e do Golfo e, segundo os autores, não é simples a explicação para a grande diversidade de populações encontradas (Hare & Avise, 1998). Além disso, dentro baia de Chesapeake, Rose *et al*. (2006) verificaram que a diferenciação genética de *C. virginica* aumentava com a distância geográfica, sugerindo que o comportamento larval seria tão importante quanto a hidrografia e que o recrutamento local seria a regra e não um fenômeno tributário-específico. A análise dos dados de microssatélites, obtidos por Yu & Li (2008), para populações de *Crassostrea plicatula* da China, detectou importante diferenciação genética entre populações separadas por menos de cem quilômetros.

A possibilidade de criação de ostras no Estado do Pará surgiu em abril de 2001 através de um projeto de pesquisa financiado pela Secretaria Executiva de Ciência e Tecnologia e Meio Ambiente (SECTAM), para a compra de equipamentos e instalação de um cultivo piloto no município de Augusto Corrêa. Em novembro de 2005 o Serviço Brasileiro de Apoio à Pequena e Média Empresa (SEBRAE/PA) e entidades parceiras promoveram uma missão técnica de ostreicultores de Nova Olinda, dentre outros municípios interessados, até o Estado da Bahia, com o objetivo de proporcionar aos seus participantes, conhecimentos e técnicas que seriam adquiridas por meio de visitas in loco (Sampaio & Boulhosa, 2007).

Desde 2006, a ostreicultura no Nordeste paraense vem contribuindo economicamente e socialmente, garantindo lucratividade para ostreicultores e o fortalecimento da cadeia com a criação de uma rede. A sustentabilidade está atrelada à preservação ambiental, no entanto, não existem trabalhos que enfoquem estudos relacionados ao mapeamento e a ecologia dos bancos naturais, o efeito de captação de sementes sobre os estoques naturais de larvas de ostra e a relação entre produtividade dos cultivos e as características do meio ambiente. Dessa forma, existem lacunas técnico-científicas sobre ostreicultura no nordeste paraense. A presente proposta de pesquisa procura preencher esta lacuna além de contribuir para o desenvolvimento de indicadores de sustentabilidade ambiental da ostreicultura.

1.2 Organização da Cadeia da Ostreicultura

No Estado do Pará a atividade do Cultivo de Ostras (Ostreicultura) é desenvolvida desde 2006 por aproximadamente 80 famílias diretamente em sete associações registradas no Cadastro Nacional de Pessoa Jurídica (CNPJ) em cinco municípios: Associação dos Agricultores e Aquicultores de Nova Olinda (AGROMAR) no município de Augusto Corrêa; Associação dos Aquicultores, Produtores Rurais e Pescadores de Nazaré do Seco (AAPPNS) no município de Maracanã; Associação de Aquicultores da Vila de Lauro Sodré (AQUAVILA) e Associação Agropesqueira de Nazaré de Mocajuba (AGRONAM) no município de Curuçá; Associação dos Agricultores e Aquicultores de Santo Antônio de Urindeua (ASAPAQ) no município de Salinópolis; Associação de Mulheres na Pesca e Agricultura de Pererú (AMPAP) e a Associação dos Produtores de Ostras de Pererú de Fátima (ASSOPEF) no município de São Caetano de Odivelas, Pará (Sampaio & Boulhosa, 2007; Hoshino, 2009; Macedo *et. al*. 2016) (Figura 1).

A área de abrangência da pesquisa é a Mesorregião do Nordeste Paraense que representa 6,7% da área do Estado do Pará, com uma área de 83.182,6 km^2 e uma população de 1.473 mil habitantes, correspondendo a 23,8% da população estadual (IBGE, 2013).

Em 2009, o SEBRAE/PA incentivou a criação da Rede Nossa Pérola com o objetivo de congregar ostreicultores e instituições envolvidas na cadeia no Estado do Para na área do ensino, pesquisa, extensão e fomento. A rede promove reuniões bimensais em diferentes municípios e as principais dificuldades apresentadas pelo setor e discutidas na rede são: legalização dos cultivos (licenciamento ambiental); financiamento (crédito); dificuldade de captação de sementes; baixa salinidade que afeta o crescimento e dificuldades na aquisição de apetrechos (insumos importados).

A produção de ostras em 2010 nos seis grupos atendidos pelo SEBRAE/PA conforme o relatório gerencial foi de aproximadamente 19.577 dúzias com a utilização de 958 apetrechos (travesseiros e lanternas) e o faturamento de R$ 39.731,00. No entanto, apenas dois cultivos de ostras (Nova Olinda e Lauro Sodré) representaram 90% da produção e faturamento no Nordeste paraense (SEBRAE-PA, 2010).

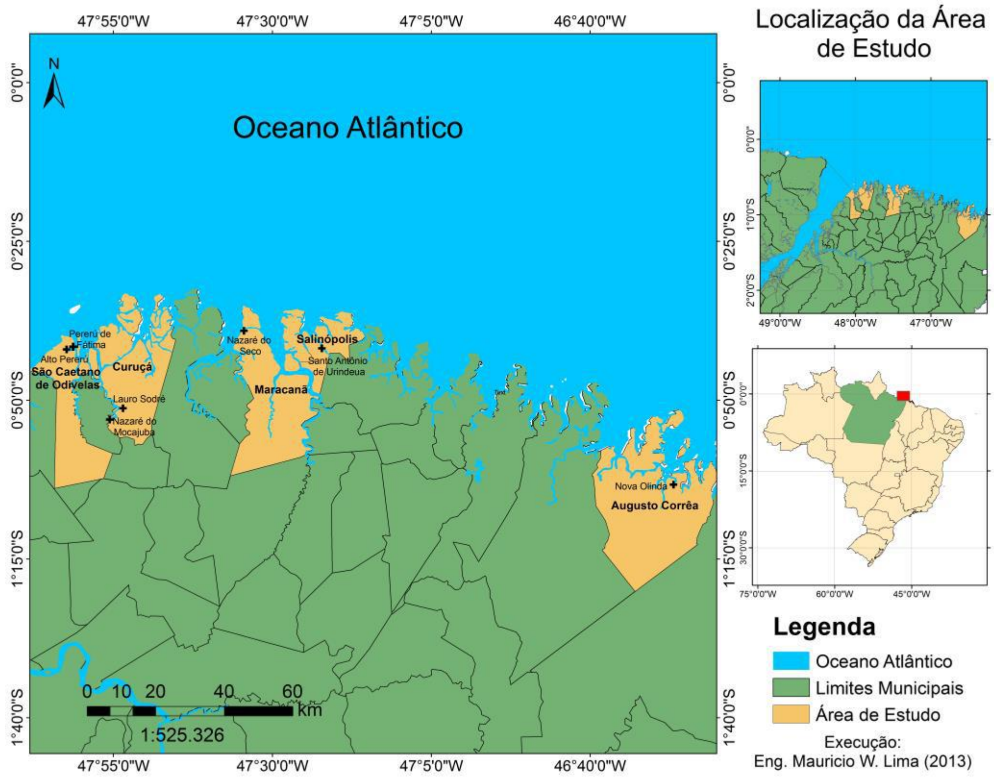

Figura 1 Localização de todos os cultivos de ostras no Nordeste Paraense.

Atualmente, a ostreicultura paraense vem se tornando uma alternativa de geração de renda para aproximadamente 80 famílias. A produção vem aumentando nos últimos anos, apesar do significativo tempo em que a atividade é exercida nessas comunidades litorâneas, a produção de ostras do Estado do Pará foi contabilizada nas estatísticas oficiais pelo Instituto Brasileiro de Geografia e Estatística (IBGE) apenas em 2013, quando totalizou 8.250 kg nos municípios de Curuçá e São Caetano de Odivelas movimentando cerca de R$ 50.000,00. Em 2015, a cadeia produtiva da Ostreicultura movimentou R$ 217.000,00 com uma produção de 38.240 toneladas nos municípios de Augusto Corrêa; Salinópolis; Curuçá e São Caetano de Odivelas (IBGE, 2014; 2015; 2016).

No Estado do Pará, na região de Curuçá e arredores, as sementes de ostras (jovens) têm sido coletadas na natureza e comercializadas para outras regiões do nordeste do Pará e também do nordeste do Brasil para fins de cultivo. Em alguns pontos de coletas (bancos), a população natural está diminuindo.

1.3 Aspectos ecológicos nos cultivos

Estudos têm evidenciado que as condições ambientais influenciam fortemente o crescimento e a sobrevivência de moluscos bivalves durante distintas fases do seu ciclo de vida. Essas condições relacionam-se aos fatores temperatura, salinidade, pH, dióxido de carbono (CO_2), presença de microalgas e composição do material particulado em suspensão (Gireesh & Gopinathan, 2004; Rivero-Rodriguez *et al*., 2007; Cáceres-Puig *et al*., 2007; Dickinson *et al*., 2012; Guzmán-Agüero *et al*., 2013; Funo *et al*., 2015).

Dentre os referidos fatores, a salinidade deve ser considerada na malacocultura, pois apresenta variações diárias e sazonais nos estuários, sendo influenciada pelo regime de marés e pelo período chuvoso, além de constituir importante fator ambiental que determina a distribuição de moluscos bivalves em ambientes estuarinos e marinhos (Vilanova & Chaves, 1988; Fuersich, 1993; Funo *et al*., 2015).

Além das marés, a sazonalidade também influencia a qualidade das águas estuarinas. A região das Reentrâncias Maranhenses e Paraenses apresenta em um determinado período chuvoso, índices pluviométricos de 2.500 mm a 2.800 mm e no período seco a precipitação pluviométrica é quase inexistente (Moraes *et al*., 2005; Moura & Nunes, 2016).

O conhecimento sobre a tolerância das ostras de importância comercial à salinidade é primordial para dar subsídio ao cultivo em larga escala. Dessa forma, algumas pesquisas foram realizadas para investigar os efeitos da salinidade em diferentes espécies de ostras

(Ramos & Castro, 2004; Bergquist *et al.*, 2006; Dove & O´Connor, 2007; Betanzos-Vega *et al.*, 2014; Funo *et al.*, 2015).

1.4 Legislação e a Ostreicultura

Segundo Ramos & Castro (2004), em muitos países existem normas baseadas em análises microbiológicas de alimentos e de água de cultivo. No Brasil, os padrões de qualidade que determinam limites dos parâmetros ou substâncias presentes dependem da classificação das águas interiores, estabelecida segundo seus usos preponderantes, conforme a Resolução nº 357/2005 do Conselho Nacional do Meio Ambiente - CONAMA (BRASIL, 2005), variando da classe especial até a classe 4.

A regularização da maricultura no Brasil passou a ter algumas diretrizes básicas desde 2003. Em 2005 foi feita uma Instrução Normativa (IN) da SEAP/PR nº. 17 (BRASIL, 2005), revogada pela Instrução Normativa de MPA nº. 08 (BRASIL, 2010). Através da IN da SEAP/PR nº. 17, foi elaborado o projeto denominado Planos Locais de Desenvolvimento da Maricultura (PLDM), que passou a ser desenvolvido no Estado do Pará desde 2008, através de convênio firmado entre o Ministério da Pesca e Aquicultura (MPA) e a Fundação de Apoio a Pesquisa, Extensão e Ensino em Ciências Agrárias (FUNPEA) em parceria com Universidade Federal Rural da Amazônia (UFRA) (I. Furtado Júnior, *com. pes*.). Os PLMD´s são instrumentos importantes de planejamento participativo para a identificação de áreas propícias à delimitação dos parques aquícolas marinhos e estuarinos bem como das faixas ou áreas de preferência para as comunidades tradicionais, com o objetivo de promover o desenvolvimento sustentável da maricultura em águas de domínio da União (BRASIL, 2005).

A principal característica de uma produção sustentável é que se assume que a natureza é finita, descartando o crescimento sem limites, característico da economia clássica. Além disso, se assume também o compromisso de que cada geração tem o dever de deixar para a próxima, uma quantidade de recursos naturais, equivalente àquela que recebeu. Esta definição, apresentada na Agenda 21[1] (da qual o Brasil é signatário) pode ser considerada universal e vem sendo adaptada pela Organização das Nações Unidas para a Agricultura e Alimentação (FAO) e outros órgãos internacionais para vários setores produtivos (Valenti *et al.* 2010).

Assim, aquicultura sustentável pode ser definida como a produção lucrativa de organismos aquáticos, mantendo uma interação harmônica com os ecossistemas e as comunidades locais. No caso do cultivo de organismos no mar e no estuário (Maricultura), para que sejam seguidos os princípios da sustentabilidade, ela deve estar baseada na produção lucrativa, na preservação ambiental e no desenvolvimento social (Valenti, 2002; 2008).

1 **Agenda 21-** É um dos principais resultados da conferência Eco-92 ou Rio-92, ocorrida no Rio de Janeiro, Brasil, em 1992. É um documento com 40 capítulos organizados em um preâmbulo e quatro seçõesque estabeleceu a importância de cada país a se comprometer e refletir, global e localmente (MMA, 2006).

2) Objetivo geral

O propósito deste estudo é caracterizar o estado atual da ostreicultura no Nordeste paraense, relacionando a produtividade dos cultivos com as características sociais, econômicas, ambientais e institucionais com o intuito de subsidiar ações de manejo com vistas a propor indicadores de sustentabilidade para a cadeia da ostreicultura.

2.1 Objetivos específicos

(i) Caracterizar a cadeia da ostreicultura em aspectos relacionadas na área social; econômica, ambiental e institucional (Capítulo 1);

(ii) Descrever e comparar os parâmetros físico-químicos da água em todos os cultivos de ostras (Capítulo 2);

(iii) Analisar a estrutura populacional e o crescimento das ostras na engorda; o assentamento das sementes de ostra nativa e exótica; o tamanho e o peso das ostras em fase de comercialização nos principais cultivos de ostras no Nordeste Paraense (Capítulo 3).

3) Material e Métodos

As atividades de campo (entrevistas; análise dos parâmetros de crescimento e das variáveis da água nos cultivos), ocorreram no período de setembro a novembro de 2013 e fevereiro a abril de 2014. A escolha desse período foi baseada nas análises dos dados de Pluviosidade (mm) das estações automáticas do Instituto Nacional de Meteorologia (INMET) do Nordeste Paraense (A202-Castanhal; A215–Salinópolis e A226–Bragança), onde se observou que o período com os maiores índices pluviométricos foi de setembro a novembro e o período com os menores índices pluviométricos foi de fevereiro a abril. Essa classificação foi feita considerando o período chuvoso e o seco regional (Moraes *et al*., 2005).

Os dados primários foram obtidos junto às associações por meio de entrevistas diretas com os ostreicultores, usando um questionário semi-estruturado com informações relacionadas à caracterização de cada entidade; informações na área social, econômica, ambiental e institucional. Os dados secundários (informações sobre produção; comercialização e dados sócio-econômicos) foram obtidos por levantamento bibliográfico e pesquisas realizadas junto a instituições (públicas ou não), que mantém os registros de apoio na cadeia produtiva desde 2006, tais como SEBRAE/PA; IBGE; Secretarias Municipais de Pesca e Aqüicultura; Secretaria Estadual de Pesca e Aqüicultura (Sepaq); Ministério da Pesca e da Aqüicultura (MPA), Prefeituras Municipais entre outros.

Dessa forma, em todos os meses mencionados anteriormente, os setes cultivos foram visitados para caracterização da água do cultivo durante a enchente e/ou vazante no período da lua cheia ou lua nova (marés de sizígia). Em cada coleta determinou-se três momentos de análise na maré enchente ou vazante (Maré 1 - M1; Maré 2 - M2 e Maré 3 - M3). Em uma linha reta na área de engorda de cada cultivo, determinamos três áreas de coleta (A1; A2 e A3) para fins de replicação espacial (Figura 2).

A temperatura (º·C); a condutividade da água (mS/cm); salinidade; potencial de óxido-redução (orp); oxigênio dissolvido (mg/l) e potencial hidrogeniônico (pH) foram mensurados *in situ* utilizando um medidor multiparâmétrico (HANNA HI-9828). A profundidade em cada coleta foi feita com o equipamento Eco Sonda Portátil, marca Speedtech (Modelo SM5).

Nos estudos de assentamento (tamanho das sementes da espécie nativa); crescimento *in situ* nos cultivos de ostras e monitoramento do tamanho comercial tipo Baby (60-79 mm) e o tamanho Médio (80-99 mm) no Laboratório de Moluscos da Universidade Federal do Pará foi utilizado paquímetro digital com margem de erro de 0,01 e para avaliar o peso das ostras foi utilizado uma balança digital com margem de erro de aproximadamente de 2g.

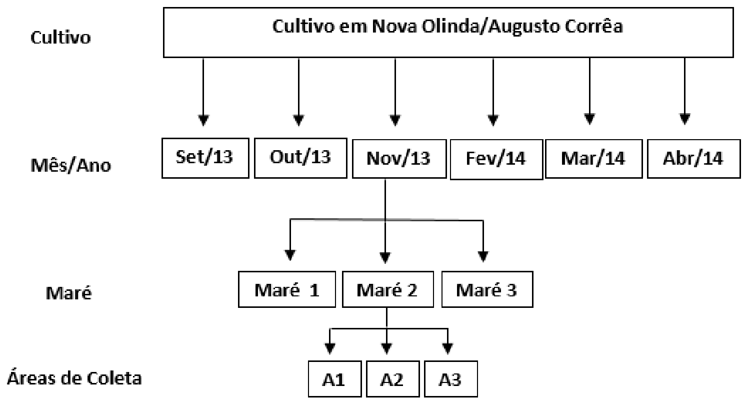

Figura 2. Esquema do desenho amostral para a análise das variáveis na água em cada um dos sete cultivos de ostras no Nordeste Paraense.

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CAPÍTULO 1

Oyster culture on the Amazon mangrove coast: asymmetries and advances in an emerging sector*

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HORÁCIO SCHNEIDER

COLIN ROBERT BEASLEY

* Submetido ao periódico científico

REVIEWS IN AQUACULTURE (QUALIS A1) – BIODIVERSIDADE

(ANEXO 01)

Oyster culture on the Amazon mangrove coast: asymmetries and advances in an emerging sector

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Running title: Amazon mangrove oyster culture

Abstract

Oyster culture activity along the eastern Amazon mangrove coast, in the Brazilian state of Pará, was evaluated by using socio-economic data to support its management and future development. Between 2013 and 2014, surveys were carried out in the region's seven oyster culture associations through interviews with the president of each association, as well as with 56 of their members (72% of the total). Further data was obtained from managerial reports of the Brazilian Support Service to Micro and Small Enterprises in Pará state (SEBRAE-PA), after being allowed by this institution. The associations Agromar, from the community of Nova Olinda, and Aquavila, from the community Lauro Sodré, stand out from the others due to their larger on-growing areas and total production in 2013. However, smaller associations are more efficient with higher production per unit area. Although associations have grown in number since 2006, along with their increased capacity and production due to governmental assistance, they need to be better organized in comparison to other regions of Brazil. The organization should include regular monitoring of growth, production and environmental variables, the development of depuration facilities, an improved distribution and an attractive presentation of products. There should be less dependence on public funding and more partnerships with private enterprises, as well as an active co-participation in the development of the corresponding legislation and public policies regulating both oyster culture and the protection of natural oyster beds.

Key words: *Crassostrea gasar*, estuary, mariculture, coastal resources, Brazil.

Oyster culture worldwide and in Brazil

Oyster culture is a traditional activity with a long history, especially in Southeast Asia (Lam and Morton 2003) and, globally, is one of the most important sectors in aquaculture (Forrest *et al*. 2009; Campbell & Pauly 2013). *Crassostrea gigas* (Thunberg 1793) is the most widely cultivated oyster species in thirty (30) countries, as well as the species with the highest production; a total of 4,288,230 tons were produced in 2010, of which 85% came from China (Barbieri *et. al.* 2014; Pauly & Zeller 2015). The other top producers of *C. gigas* in 2010 were South Korea, Japan, France, Thailand, Mexico, the United States, Canada, Ireland and the Netherlands. Up to eight (8) species of *Crassostrea* are cultivated worldwide, for example, production of *Crassostrea virginica* (Gmelin, 1791) in the United States was 108.300 tons in 2010 (Campbell & Pauly 2013).

In Brazil, two native *Crassostrea* species, *Crassostrea. rhizophorae* (Guilding, 1828), and *Crassostrea gasar* (Adanson, 1757), synonymous with *Crassostrea brasiliana* (Lamarck, 1819), as well as the exotic *C. gigas* (Thunberg, 1793) are cultivated. Originally from the Pacific, *C. gigas* is cultivated in the cooler waters of the southern Brazilian States Brazil, where *C. gigas* grows best (Ostrensky & Borghetti 2008; Barbieri *et al*. 2014). Santa Catarina state is the largest producer of oysters in Brazil, employing 5,000 people and producing 3,670 tons in 2014, mainly *C. gigas*. This represents a record increase of 25.17% in relation to production in 2013 (2,932 tons) (Santos & Costa 2015; Suplicy *et al*. 2015). Putting this in perspective, in 2010, Brazil produced 1,500 tons of *C. gigas* and 400 tons of the native species *C. rhizophorae* (Campbell & Pauly 2013). As such, this reveals a major asymmetry in the oyster culture sector in Brazil: a high level of investment in the production of an exotic species concentrated in Santa Catarina and a much lower and diffuse investment in the culture of a native species in remaining coastal states.

From a socio-economic point of view, a characteristic of native Brazilian oyster culture is that the majority of culture systems are very rudimentary, with a low level of investment and mechanization, most of which merely complement other forms of income, usually farming (Tureck et al. 2014). Generally, the oyster culture units are run by associations from small communities or, are family-based (Hoshino 2009; Mendonça & Machado, 2010; Macedo et al. 2016). However, such small-scale units, largely aided by government incentives, have greatly contributed to the dissemination of native mangrove oyster culture along the Brazilian coast (Pereira & Rocha 2012). The native mangrove oyster C. gasar has been cultivated on a small-scale in southeastern and southern Brazil for some time now (Muniz et al. 1986; Absher et al. 2000; Christo & Absher 2006), and there has been a recent surge in research on its culture, especially in Santa Catarina and Paraná (Silveira et al. 2011; Lopes et al. 2013; Ramos et al. 2013; Ramos et al. 2014; Gomes et al. 2014;

Tureck et al. 2014; Castilho-Westphal et al. 2015; Silva et al. 2015). Still, production of the mangrove oyster C. gasar remains low, perpetuating the asymmetry in Brazilian oyster production.

Brazil produced 19,360 tons of mollusks (oysters, scallops and mussels) in 2014 (IBGE 2015) with Santa Catarina leading with 97% of the total, followed by Paraná (266 tons, 1.37%), Rio de Janeiro (93 tons, 0.48%) and São Paulo (88 tons, 0.45%) in the South East and Bahia (64 tons 0.33%), Alagoas (14 tons, 0.07%) and Rio Grande do Norte (9 tons, 0.05%) in the North East, and finally, the state of Pará in northern Brazil, with 8 tons (0.04%). This represents another asymmetry, mangrove oyster culture in Pará is only recently emerging, since 2006, which is surprising given it's relatively well conserved mangrove coast and relatively low impact of urban and industrial development there, in comparison with the rest of the Brazilian coastline (Tenório et. al. 2014; Ferreira & Lacerda 2016). Molluscan seed production in Brazil in 2013 (IBGE 2014) was similarly asymmetric with 92.5% concentrated in the municipality of Florianópolis (Santa Catarina), 6.2% in the municipality of Angra dos Reis (Rio de Janeiro), and, significantly, 1.6% in the municipality of Curuçá (Pará). The latter is the only supplier of Crassostrea gasar seed harvested from the wild, whereas both the former supply laboratory-raised seed, mostly C. gigas (IBGE 2014), but C. gasar seed production trials have been carried out in Santa Catarina (Silveira et al. 2011; Tureck et al. 2014).

Despite growth in oyster culture in Brazil, mentioned above, there are a number of weaknesses in the sector, which is in need of strategic planning, with a view to avoiding possible conflicts and/or the elimination of small-scale units, should operations on a larger, more industrial scale come into effect (Ostrensky & Borghetti 2008). Environmental degradation of mangroves and coastal pollution are of considerable concern along the Brazilian coast (Souza 2009; Rovai *et al.* 2012). Losses of South American oyster beds have been inferior to 50% but despite the relatively better status in relation to other continents, there is little or no regular monitoring (Carranza *et al*. 2009; Beck *et al*. 2011). The São Paulo and Paraná coasts are the only locations in Brazil where, since 1987, legislation has been in place to protect natural oyster beds (Mendonça & Machado 2010). As an aid to planning and development of mariculture in Brasil, in 2003, the Federal government adopted the Plano Local de Desenvolvimento de Maricultura (PLDM) or Local Mariculture Development Plan, in English, which is elaborated in conjunction with local partnerships with the aim of evaluating the potential for mariculture and the delimitation of culture units in each state (Novaes *et al*. 2011; Vianna *et al*. 2012; Suplicy *et al*. 2015). Such plans have been carried out in some Brazilian states, but Santa Catarina is at the forefront of this process and, since 2007, has fully implemented a PLDM with other coastal management schemes such as the Coastal Zone

Management Plan (Vianna *et al*. 2012), for example, and should be in a position to lead the sector into a cycle of both ecologically and socio-economically sustainable growth (Suplicy *et. al*. 2015).

A short history of the development of oyster culture in Pará state

The then *Secretaria de Estado de Ciência Tecnologia e Meio Ambiente* (SECTAM), or Executive Secretariat of Science, Technology and the Environment, in English, a state body, now restructured, responsible for supporting sustainable scientific development, financed initial studies of oyster culture in Pará, from April 2001, for equipment and pilot cultures in the municipalities of Augusto Corrêa and Magalhães Barata (Alcântara-Neto 2003). The *Serviço Brasileiro de Apoio às Micro e Pequenas Empresas* (SEBRAE), or Brazilian Support Service to Micro and Small Enterprises, in English, is an autonomous body that supports small enterprises. In November 2005, together with municipal authorities, the Federal University of Pará (UFPA), and the agri-aquaculture association AGRONOL, now called AGROMAR, and the Pará branch of SEBRAE (SEBRAE/PA) brought members of several communities from Pará on a fact-finding technical visit to oyster culture facilities in Bahia state, on the east coast of Brazil (Sampaio & Boulhosa 2007). In 2006, SEBRAE/PA began formal support for groups interested in oyster culture and provided the incentive for the creation of a network called “Rede Nossa Pérola” (RNP), or Our Pearl Network in English, in 2009, bringing together oystergrowers from the municipalities of Augusto Corrêa, Maracanã, Curuçá, São Caetano de Odivelas. Members of institutions in Pará state involved in oyster culture and aquaculture through teaching, research, outreach and funding also participated regularly in the RNP, although, from 2010 onwards, the RNP statutes were changed to specify involvement of educational institutes on an *ad hoc* basis only. The RNP meets every two months in different municipalities and the main difficulties presented by the sector and discussed in the years following its establishment, included legalization of culture units (including environmental licensing), funding and credit, difficulty in harvesting seed, problems with low salinity, which affects on-growing, and difficulties in acquiring materials and equipment, which are generally imported (Sampaio & Boulhosa 2007; Hoshino 2009).

Three community oyster culture projects from the municipalities of Augusto Corrêa, Maracanã e Curuçá, along the Pará coast, and that had been in operation for over two years, were evaluated by Hoshino (2009). The oyster growers are mostly small farmers, artesanal fishermen, which supplement their family diet and income through oyster culture. Many oyster growers stated that as soon as they could increase production, they would dedicate themselves exclusively to this activity (Hoshino 2009). The project at Curuçá is noteworthy since it has the largest number of natural oyster beds in the region and this is the origin of all seed for on-growing in Pará, as well as a smaller proportion that is exported to other states (França *et. al.* 2011; Lopes *et. al*. 2013).

As interest in oysters and their potential for culture in Pará increased, research projects on oysters in the region began to evaluate oyster genetics, settlement and reproduction. Molecular genetics has revealed there are two native species of oyster in northern and northeastern Brazil, *Crassostrea gasar* (Adanson, 1757), *syn. Crassostrea brasiliana* (Lamarck, 1819) and *Crassostrea rhizophorae* (Guilding, 1828), the former predominant and the latter uncommon along the Pará coast (Varela *et al.* 2007, Melo *et al.* 2010, Melo *et al.* 2013) However, additionally, an exotic species of *Crassostrea* was detected in the municipality of Bragança, Pará (Varela *et al*. 2007; Gardunho *et al*. 2012). In terms of oyster recruitment, Marques-Silva *et al*. (2006) found that settlement of *Crassostrea* was greater in the dry season and on the undersides of wooden substrates placed closest to the bottom of mangrove tidal creeks in Bragança, Pará. In the same area, show that, between 2000 and 2005, peaks in settlement of *Crassostrea* occurred between September and December, when salinity was highest, but that numbers settling tended to decrease over this 5 year period. Paixão *et al*. (2013) noted that seasonal changes in rainfall and salinity accompanied gonadal maturation in *C. gasar* from Nova Olinda, Augusto Corrêa, Pará and that the best time for harvesting seed from the water column was during the dry and dry to wet periods of the year. In contrast, Gardunho *et al*. (2012) found that seed of the exotic *Crassostrea sp*. settling on a mangrove island, Ilha Canela, Bragança, Pará was abundant and regular in these waters, which have a relatively constant higher salinity (>20) throughout the whole year, in comparison with locations on the coast which vary between 0 and 40 (Cohen *et al*. 1999; Funo *et al*. 2015; Monteiro *et al.* 2016; Moura & Nunes 2016) and in some places up to 50 (Lead author, pers. obs.).

In Pará state, planning for mariculture, via the PLDM, was carried out between 2008 and 2012, through an agreement between the now extinct Ministry of Fisheries and Aquaculture (MPA) and the *Fundação de Apoio a Pesquisa, Extensão e Educação na Ciência Agrícola* (FUNPEA), or Foundation to Support Research, Extension and Education in Agricultural Science, in partnership with the Amazon Rural Federal University (UFRA). According to an unpublished report from the Ministry of Fisheries and Aquaculture, the study identified a total of 171 ha of coast favorable for the development of oyster culture and proposed 16 oyster culture parks distributed among the municipalities of Curuçá, Salinópolis, São João da Ponta and São João de Pirabas. However, the PLDM in Pará state was not developed in a fully participatory or integrated manner with local stakeholders. Traditional coastal communities that were active in the sector since 2006 did not take part in the elaboration of the PLDM, nor were their culture units included in the aquaculture parks delimited along the Pará coast. Furthermore, although a preliminary proposal was presented to the public in Bragança, the final result was not.

Currently, there are seven oyster culture associations in five municipalities, all of which, except one in Salinópolis, are located in a Marine Extractive Reserve (RESEX), which are areas designated for management by the users of resources within the reserve (Senado Federal, 2008). However, there are problems related to the environmental and economic sustainability of oyster culture in Pará state, such as, the unregulated exploitation and lack of environmental legislation governing the use of natural oyster beds, as well as conflicts between those that exploit natural beds and the oyster growers. There are also problems with the regularization of the activity and the producer, the lack of full-time oyster growers as well as a lack of investment of private capital, which may be hampering development of the sector. As an example to be followed, France, the largest oyster producer in Europe (Bihan *et al*. 2013), has a long tradition in the sector, dominated by relatively small family-run businesses where investment of private capital was essential to driving the industry forward (Buestel *et al*. 2009). Considering the relatively recent development of oyster culture in Pará state, and the challenges facing the sector there, the objective of the present study was to evaluate oyster culture activity along the Pará coast, to provide information for management and suggest priorities for its future development.

Study area, survey and analysis

The study covers the northeastern coast of Pará state, representing 6.7% (83,182.6 km^2) of the total area of Pará, and which has a population of 1.473 million inhabitants, or 23.8% of the state population. Surveys were carried out in each of the seven oyster culture associations in five municipalities in the region (Table 1; Figure 1). Fieldwork took place between September 2013 and April 2014, during which two visits were made to each oyster culture association. The president of each association was interviewed separately to obtain primary data by means of semi-structured questionnaires (Viertler 2002) with the aim of describing the sector with respect to social organization, infrastructure, production and commercialization, relationships with other organizations, adherence to current legislation and perspectives for the future. During the visits, additional interviews were carried out with 56 oyster growers (see Table 1 for breakdown among associations).

Data on production, commercialization and infrastructure at each association between 2011 and 2013 were provided on request by SEBRAE/PA (2014), which included the number of oyster seed (in thousands) in stock, the number of adult oysters (dozens) sold, the most commonly commercialized size of oyster (Baby, 60-79 mm; Medium, 80-99 mm and Master, above 100 mm), market diversity (number of markets, i.e., number of municipalities or communities, not individual clients), as well as the number of lanterns and bags used for on-growing. Mean number of days spent in maintenance, and whether or not the association receives government technical assistance were obtained from interviews. The on-growing area (m^2) was calculated from coordinates obtained with a portable geographic positioning system at each association. Variables related to social organization were obtained for each association as follows: number of members actively engaged in oyster culture, mean age of oyster growers, the coefficient of the proportion of male and female members, the percentage of members in the following age classes: 20-40 yr, 40-60 yr and above 60 yr, year of establishment, year when oyster culture began and the percentage of members with access to government financial assistance.

All nominal and ordinal variables were numerically coded in order to quantify the response. The data from each association were used to generate a dissimilarity matrix based on Euclidean distance in order to quantify the relationships among associations. Variation among associations in terms of the data was evaluated with classification by hierarchical agglomerative clustering with average linkage and ordination by non-metric multidimensional scaling using the package *vegan* (Oksanen *et al*. 2017) in GNU-R (R Core Team 2017) and the Euclidean dissimilarity distance matrix as input.

Results

Legal status and social organization

As of 2013, all seven oyster culture associations have been registered with the Brazilian National Register of Legal Entities (Cadastro Nacional de Pessoa Jurídica – CNPJ). The first register was in 1999 and the most recent in 2012. From 2006, four oyster culture associations were registered with the CNPJ. Thus, all seven are recognized as registered associations, members of which may go about their activities producing oysters, however, legally, the associations are not commercial enterprises. In Brazil, only cooperatives and businesses are allowed to commercialize their products However, a transition from an association to a commercial entity may be difficult, since in all seven associations, each oyster grower is responsible for the production and commercialization of their own oysters. This is an unusual situation in mariculture, where labor is generally carried out collectively by members of the community (Singer 2000), thus facilitating the transition to a cooperative.

At present, there is a total of 184 members among all seven associations which are involved in agriculture and/or oyster culture. Of this total, 43% (79 members) participate predominantly in oyster culture. During the study, 72% of the 56 interviewees indicated that, although oyster culture was their main economic activity, they have other business interests or activities, the most important of which is family-based agriculture. Among coastal communities near mangrove areas, small-scale farming is the principal activity in the region, or in other words, is a permanent, year-long activity for the whole family (Glaser 2003; Blandtt & Sousa 2005). Family-based plantations of beans, manioc, and rice, among others, is the main source of income in all seven oyster culture associations in Pará. The complementary nature of shellfish culture is common in Brazil, for example, Fagundes *et al.* (2004) observed that the main activity of mussel growers in São Paulo state was fishing. As an example in Pará, the association AGROMAR from the community of Nova Olinda in the municipality of Augusto Corrêa had 15 members in 2015, for which oyster culture was a full-time activity for 6 members and a secondary activity for the remainder. Only two members had a monthly income of over 1 minimum salary (Brazilian Real R$ 788,00 in December 2015), both of which were full-time oyster growers.

Among the oyster growers interviewed, 71% are male and 29% female and the latter corresponds to the 28%, reported for female participation in the labor force among coastal communities in Latin America (Abramo 2007; Leitão 2013; Alves & Pontes 2015). In other regions of Brazil, female participation in oyster culture is lower that that recorded in Pará. For example, 21.4% in Cananéia, São Paulo (Mendonça & Machado 2010) and only 9.1% in Baía de Ilha Grande, Angra dos Reis, Rio de Janeiro (Moschen 2007). Among the seven associations in Pará, there is no division of labor among male and female oyster growers and only a single association, ASSOPEF, in the municipality of São Caetano de Odivelas, had no female members.

Among interviewees from all seven oyster culture associations in Pará, age ranged between 27 and 68 yr for women, and 23 and 71 yr for men, with mean ages (±SE) of 48.3 (±12) and 40.9 (±12) yr, respectively. Although Amorim (2007) did not present data on the age of male participants, the age of female participants in the mariculture sector of Santa Catarina state, most of which were aged between 41 and 50 years, similar to the mean age of women involved in the sector in Pará. Among the associations, the lowest mean age, 38 years, was recorded for the association AQUAVILA in the municipality of Curuçá and the largest mean age, 52 years, for the association ASAPAQ in the municipality of Salinópolis (Table 2).

In the present study, 55% (31) of the interviewed oyster growers did not complete primary education (Figure 2), most of which were distributed among the associations AGROMAR (9), AQUAVILA and ASSOPEF (6 in each), and AMPAP (4). Only a single oyster grower, from AGROMAR, did not receive any formal education, self-declaring illiterate. All of the communities with oyster culture associations also have access to municipal schools with primary education. However, the above situation is common in communities in Pará that are dependent on the mangrove ecosystem, where school-goers often abandon their studies early to begin work in order to supplement their families' incomes (Blandtt & Sousa 2005). However, 12 association members (21%) completed secondary school and two members (4%), one each from AGROMAR and ASSOPEF, completed a third level course, both being school-teachers (Figure 2). The community of Nova Olinda in the municipality of Augusto Corrêa, is the only one with access to secondary education through a state school.

In relation to governmental assistance, 56% of those interviewed (43 members) have access to programs run by the federal government, such as the Family Welfare (Bolsa Família), which provides a guaranteed minimum income for families that varies with the number of children and adolescents attended, as well as with the level of poverty. Such programs are focused on the poorest sectors of society and demand only that the family maintains their dependents in school, and not involved in illegal underage work, and up-to-date with vaccinations and medical exams Castro *et al.* (2009), Bolsa Família Project website: http://www.caixa.gov.br/programas-sociais/bolsa-familia/Paginas/default.aspx) thus contributing not only to raising families involved in oyster culture in Pará above the poverty line, but also to improving their education and health.

In terms of experience in the sector, 46% of the interviewees have been involved for between 4 and 6 years, 27% for between 2 and 4 years and 27% for up to 2 years. As oyster culture in Pará is a relatively recent activity, having begun in 2006, it is relevant that almost half of those interviewed have at least 4 years experience in the sector. By comparison, 62% of mussel-growers from the São Paulo coast, an activity that is long established there, have 5 years experience (Fagundes *et al.* 2004).

Exploitation of oyster beds and conflicts with oyster growers

Social instability in coastal communities in Pará state with poor social support is indicated by increased poverty, migration and violence (Grasso 2005). Increasing population growth and, as a consequence, greater competition for natural resources, have increased conflict within and among coastal communities in Pará (Glaser 2003). The exploitation of oyster beds is an important example. In Brazil, lime derived from the shells of marine bivalves had been used since colonial times in the mortar and plaster of buildings, fortifications and houses. However, from the 1950s, the Brazilian cement industry emerged and the old lime factories (caieiras) began to disappear (Kanan 2008). Oyster growers from all seven associations in Pará reveal that lime used to be extracted from oyster shells up to around 20 years ago. However, exploitation of oyster beds for consumption or sale as food still occurs and in the municipalities of Augusto Corrêa, Curuçá and Magalhães Barata, the disappearance or reduction in natural beds of oysters has been noted by locals (Lead author, pers. obs.). Of these municipalities, Magalhães Barata is the only one not to have an oyster culture association, but exploitation of oyster beds occurs there, and, over the past 20 to 30 years, coastal communities from Maracanã and Magalhães Barata have been commercializing oysters from natural beds for the restaurant industry in the state capital, Belém. In Vila de Lauro Sodré in the municipality of Curuçá, there are, on the one hand, harvesters, locals that exploit natural oyster beds for over 20 years, and, on the other, members of the association AQUAVILA that have been carrying out oyster culture since 2006 (see Table 1), and exploitation of oyster beds before that. However, it should be noted that only 4 members of AQUAVILA are involved in oyster bed exploitation (Reis 2015).

In recent years, several conflicts and disagreements have arisen among harvester and oyster growers in Vila de Lauro Sodré, Curuçá, specifically in the Reserva Extrativista Marinha Mãe Grande de Curuçá. The oyster growers accuse the harvesters of removing large quantities of oysters, thus damaging natural beds as well as seed production. Up to 2015, AQUAVILA was the only association in Pará to commercialize seed both inside and outside the state (IBGE 2014). Reis (2015), in her anthropological study of the social organization of the production and sale of oysters from Curuça, noted that the association AQUAVILA entered the conflict probably as a result of concern over a potential reduction in seed production due to the exploitation of the natural beds. This is of course relevant due to the absolute dependence of all the other oyster culture associations on the supply of seed from AQUAVILA, which, if interrupted, may abruptly terminate oyster culture in Pará.

The harvesters from Lauro Sodré argue that they only remove small quantities of oysters, as a complement to their income from agriculture (Reis 2015). The inhabitants of the reserve, who see themselves as farmers that exploit oysters to sell at weekends, reinforce this idea: "... I don't depend on the oyster to live; I guarantee the sustenance of my family through agriculture the whole week, the sale of oysters is a complement to pay an installment and other things we may need" (Reis 2015). In interviews in the present study, around 30 harvesters in Lauro Sodré, Curuça, sustain their families with income solely from the sale of exploited oysters. Furthermore, Reis (2015) recorded that the harvesters accuse members of the oyster culture association AQUAVILA of the removal of large quantities of oysters every week, which is impacting oyster beds in the region. Reis (2015) notes that while harvesters of natural oyster beds are invariably labeled villains by both AQUAVILA oyster growers and consultants from SEBRAE/PA, some AQUAVILA members also harvest oysters from natural beds. The conflict in Curuça continues to persist and unless an objective mediator steps in, it is unlikely to be solved in the near future.

Interviews during the present study have shown that over the past 10 years, AQUAVILA was the only association that manged to expand its market for oysters as far as the municipality of Marabá (around 500 km to the south) and this market penetration has probably been possible via the sale of oysters that are cultivated and also exploited from natural beds (Lead author, pers. obs.). One of the reasons for this is that the AQUAVILA on-growing area is far from the seed-harvesting site and this limits their production of adult oysters. Facilities are, however, now being built to allow oyster growers to stay over at the on-growing site, which may increase the output of cultivated oysters from AQUAVILA in the near future.

Fortunately, the conflict between harvesters and oyster growers in Lauro Sodré has not been seen in other municipalities, despite the presence of harvesters in São Caetano de Odivelas, Maracanã, Salinópolis and Augusto Corrêa (Lead author, pers. obs.), where oyster culture also occurs. Little is known of the impact of exploitation of oyster beds in the region and there is no evidence to suggest that the harvester is causing an impact on the beds. In fact, harvesting of oysters is not prohibited in Brazil as, up to now (2017), there is no legislation linked to the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBIO) nor any fisheries agreement regulated by the Instituto Brasileiro de Meio Ambiente (IBAMA) relating to the protection of natural beds of oysters. The only legislation in existence in Brazil dates from the 1980s and protects natural beds of oysters along the Cananéia (São Paulo state) and Paranaguá (Paraná state) coasts (Mendonça & Machado 2010). The manager of the marine reserve Resex de Mandira in Cananéia, Marco Aurélio dos Santos in an interview during the present study in 2013, that this legislation is actually quite effective. Subsequently, this was communicated this legislation to the associations, SEBRAE and ICMBIO in Pará and via several meetings since then, it was decided to begin development of similar legislation for coastal areas in the state of Pará. In March 2016, an initial meeting on developing protective legislation for oyster beds was hosted by ICMBIO in Belém, Pará. An outreach project, involving the Universidade Federal do Pará and the seven oyster culture associations approved for funding in March 2016 and coordinated by the lead author of the present study, aims to increase support for the protection of natural oyster beds in areas where oysters are cultivated.

Availability of infrastructure, production and commercialization

Since 2006, oyster grower associations in Pará state had only been able to acquire material for on-growing either through research projects or agreements with federal, state or municipal bodies and/or institutes involved in research and education. The most recent agreement in place is that signed in 2009 involving the now extinct Ministry for Fisheries and Aquaculture, Ministério da Pesca e Aquicultura (MPA), Secretary for Fisheries and Aquaculture of the State of Pará, Secretaria de Pesca e Aquicultura do Estado do Pará (SEPAq) and SEBRAE/PA. However, the oyster growers only began to receive the material (bags and lanterns for on-growing) from 2013 onwards. The MPA and SEPAq were incorporated into the Ministry for Agriculture, Supply and Livestock-Ministério da Agricultura, Abastecimento e Pecuária (MAPA) and the State Secretary of Agricultural and Fisheries Development-Secretária Estadual de Desenvolvimento Agropecuário e de Pesca (SEDAP), respectively. Two on-growing systems are used in oyster culture in Pará state. The fixed table is a static system with bags used in areas with wide tidal variation (BMLP 2006) and is used by 6 associations whereas the long-line system is a suspended system in the water column with lanterns and/or bags used in deeper waters and currently only used by AGROMAR (Figure 3).

Data from SEBRAE/PA (2014), show that in 2011, oyster culture associations in Pará possess a total of 927 bags for on-growing. After receiving funding via MPA-SEPAq-SEBRAE/PA from 2013 onwards, the sector had an on-growing capacity of 7,526, representing an increase of over 700% in 2 years (Table 3). In light of this, SEBRAE/PA forecast oyster production in Pará at around 40 tons in 2014 but this goal was not reached and no explanation offered in the 2015. Thus, although on-growing capacity has increased significantly, actual production appears related to management conditions where low levels of practical skills and dedication to the activity, as well as low maintenance frequency, result in lower production. Only two associations of oyster growers (AGROMAR and AQUAVILA) are relatively more advanced in terms of management, for example, regular cleaning of equipment as well as planning ahead using data from past production records.

All seven associations increased their productive capacity from 2011 to 2013, especially AGROMAR with 1,775 bags in 2013 (Table 3). The association with the least number of on-growing bags is AGRONAM, which was the last one to join RNP. With the largest number of on-growing bags and the greatest number of producers dedicated to management, according to a personal communication from SEBRAE/PA, the association AGROMAR has regularly had a member among the top three producers over the last few years. In 2013, the now extinct MPA delivered new on-growing bags to associations via an agreement with the state government (Convênio 039/2009) on condition that the oyster grower deliver, in return, information on production every two months.

During the study period, AQUAVILA from Lauro Sodré, in the municipality of Curuçá, was the only association that, besides being involved in on-growing, also carried out harvesting of seed (up to 29 mm) from the wild. This association worked with approximately 3000 artificial seed collectors with the expectation of increasing this to 5,000 collectors in 2016 according to the member Sr. José da Silva Galvão (AQUAVILA).

In 2013, AQUAVILA was reported by IBGE (2014) to have sold 900,000 seed, whereas a figure of 596,000 seed was reported by SEBRAE/PA (2014), the former an official figure, whereas the latter is an extra-official figure, divulged through the RNP, which was obtained with permission from SEBRAE/PA. Considering only the data from SEBRAE/PA (2014), the oyster seed harvest from the wild increased by 360% between 2011 and 2013. All oyster culture associations, except AAPPNS, increased their stock of seed, purchased exclusively from AQUAVILA, which increased it's harvest over the same period (Figure 4). AGROMAR now only buys juveniles, which are more expensive than seed but reach minimum market size, in about 3-4 months from the date of purchase. Most restaurants owners prefer to purchase Baby sized oysters, which are smaller in size and a dozen fit easily on a plate. However, private consumers prefer medium sized oysters.

Although there are natural oyster beds close to all culture units in Pará, the oyster growers consider these to be, in their words, “weak” and the seed of “low quality”. As a result, over the past 8 years, most associations have focused on the on-growing of oysters, whereas AQUAVILA focused on supplying seed, and was the only supplier in the region until recently. In 2016, the association AGRONAM from Nazaré do Mocajuba in the municipality of Curuçá, has begun supplying seed to associations for on-growing. Low salinity during the rainy season around the communities of Nazaré do Mocajuba and Lauro Sodré in the Curuçá region, means seed harvesting in more profitable than on-growing adult oysters. The potential of this region for seed harvesting is very high as demonstrated by Lopes (2011) and França *et al.* (2011). Several communities from the municipality of São João da Ponta, around 20 km from Nazaré do Mocajuba and Lauro Sodré in Curuçá, are interested in seed harvesting, according to an analyst at ICMBIO (Waldemar Londres Vergara Filho, pers. comm.). However, because these communities are so close, there is potential for competition for harvesting sites. Moreover, an over-dependence on seed from a single location in Pará is undesirable since disease, environmental variability, human impact and exotic species could potentially reduce seed supply from this location, bringing the sector to a halt.

Gardunho *et al.* (2012) describe the events leading to the detection of a *Crassostrea sp*., which appears to be an exotic species, occurring on a mangrove island in the municipality of Bragança, Pará, but also found in southern China (Liu *et al.* 2011) and is now also found in São Paulo. Oyster growers report that *Crassostrea sp*. is also found at all associations in Pará and 68% of oyster growers say they are able to distinguish between the seed of the exotic species and that of the native species *C. gasar*. The remainder, 32%, are unable to distinguish between the two species as a result of a lack of experience due to being engaged in the activity for only a short length of time. In the past, the lack of ability to identify the exotic species lead to a lack of productivity. Today, when in doubt, the oyster grower waits for a few days for the seed to develop since the exotic seed does not grow as fast as the native species. However, no study has been carried out so far to determine if oyster growers are indeed able to correctly distinguish between the two species. For the moment, it appears that there should be no cause for preoccupation in the sector due to *Crassostrea sp*. since most oyster growers are able to quickly weed out the exotic species and the fact that it appears to be most abundant only where salinity is constantly above 20 (Gardunho et. al, 2012). Along most of the coast, there is large variation in salinity (0-50, Lead author, pers. obs.), which does not allow populations of *Crassostrea sp*. to establish themselves permanently. However, there is a need for more vigilance on the part of port authorities to guard against further invasions of exotic species, as well as resistance on the part of oyster growers to accept seed or adults from other regions of Brazil, or other exotic species for culture. In south-east Australia, decreases in the production of the native *Saccostrea glomerata* have been attributed to a number of causes, including the introduction of *Crassostrea gigas* (Schrobback *et al.* 2014). A code of conduct for marine introductions and transfers for aquaculture has been recommended by the International Council for the Exploration of the Sea (ICES 2004).

Much of the discussion above relates to risks and requires that oyster growers adopt risk perception and management strategies to safeguard their activity, which is necessary even in countries, such as France (Bihan *et al.* 2013), where there is a much longer tradition of oyster culture. At present the oyster culture sector in Pará is extremely vulnerable to disturbance and needs to be aware of and plan for potential risks. The asymmetry in relation to oyster seed supply in Pará, where the association AQUAVILA dominates, is a weakness in the sector and the participation of more associations in seed harvesting and supply would help strengthen the sector, especially when these are from different locations along the Pará coast.

With regard to sales of seed and juveniles, the value of the *milheiro* (defined as 1000 seed, up to 29 mm, or juveniles, up to 30 to 59 mm) was established by means of an agreement between technical staff at SEBRAE/PA and the Associations at an RNP meeting. By the end of the 2nd quarter of 2015, a *milheiro* of seed was worth Brazilian Real R$30 and a *milheiro* of juveniles was worth Brazilian Real R$60 in Pará state (Figure 4).

The effect of the increase in on-growing capacity from 2013 is expected from 2014 but to date, no information on oyster culture in Pará from 2014 onwards has released by SEBRAE/PA. The absence of information is another significant weakness in the sector. Currently, there is no official publication of fisheries and aquaculture statistics obtained by SEBRAE/PA, and regular publication of a such a document would greatly facilitate diffusion of information and help speed up decision-making and investments in relation to the sector and potential partners. Over the past 10 years, strategic information on the oyster culture industry in Santa Catarina has been divulged through publications such as that of EPAGRI (2015) (www.epagri.sc.gov.br) and the oyster culture sector in Cananéia, São Paulo via the Instituto de Pesca de São Paulo (www.propesq.pesca.sp.gov.br) from which reports are regularly released on-line.

The performance of each oyster grower in terms of production is directly linked to their involvement in management and availability of on-growing potential (number of bags and physical area). Adult oysters are sold exclusively within Pará state, as far as Marabá, about 600 km from the nearest on-growing site. Seed, however, are sold both within Pará state (Brazilian Real R$ 30 per milheiro), as well as outside the state (Brazilian Real R$60 per milheiro). The associations in São Caetano de Odivelas, ASSOPEF and AMPAP, are nearest to the state capital, Belém, approximately 100 km, whereas the most distant is AGROMAR in Augusto Corrêa, approximately 270 km from Belém. Difficulties with transport infrastructure and the logistics of the supply of live oysters to the market is another weakness in the sector, since many of the associations lack vehicles and/or are located in areas with poor road access. Both of these problems are unlikely to be solved in the near future.

The production of adult oysters (in numbers of dozens) in Pará increased by 17% between 2011 and 2012 but fell by 10% from 2012 to 2013. The reason for the fall in production was not released by the Our Pearl Network but the decrease occurred in five associations (Figure 5). Only ASSOPEF and AGRONAM increased production over the period, with AGRONAM being a newcomer to the sector in 2013 (Figure 5). According to SEBRAE/PA (2014), the association with the greatest total production was AGROMAR with 9,480 dozen oysters in an area of approximately 8,725 m^2 and the association with the lowest production was AAPPNS in Maracanã with 167 dozen in an area of approximately 370 m^2. However, examining production relative to on-growing area, the most efficient units by far are AGRONAM and ASAPAQ, which produce 8.1 and 12.7 dozen oysters per m^2 (Figure 6). On the other hand, associations such as AQUAVILA e AGROMAR, which have the largest on-growing areas, could potentially be much more efficient. Besides having the largest number of partnerships with other institutes, AGROMAR and AQUAVILA, social, economic, commercial and institutional data from each association show that AGROMAR and AQUAVILA are distinct in terms of on-growing area, and total production in 2013 (Figure 6). However, in contrast, AGRONAM and ASAPAQ, are characterized by much higher per unit area production. With greater efficiency, associations should consider becoming cooperatives if the members are interested in market expansion, since under Brazilian law, associations are not-for-proit organizations, whereas cooperatives are commercial entities (Frantz 2012).

As regards commercialization and marketing, SEBRAE/PA created the brand Nossa Pérola (Ostra da Amazônia) or Our Pearl (Amazon Oysters) and proposed strengthening commercialization and sales of oysters cultivated by association members of RNP. In 2010, SEBRAE/PA elaborated three commercialization strategies: a) capacitate oyster growers to better showcase their products, b) provide supporting materials for use by associations in divulging the brand Nossa Pérola and c) develop other strategic marketing actions. The latter includes organizing oyster festivals, for example, the II Oyster Circuit (*Circuito da Ostra*) in Salinópolis in 2017, and degustation events throughout the year organized through SEBRAE/PA and the Associação Brasileira de Bares e Restaurantes (Abrasel), or in English, the Brazilian Association of Bars and Restaurants. Although the brand Nossa Pérola (Ostra da Amazônia) has not been officially registered at the Instituto Nacional de Propriedade Intelectual (INPI) or National Institute for Intellectual Property, a restaurant owner in Belém has noted that use of the brand Nossa Pérola - Ostra da Amazônia (via the placement of the logo on his marketing materials) increased sales of oysters by over 200%. Each association carries out its marketing independently, but use of a flyer is the most common form of marketing. The associations could negotiate the use of the flyer directly on restaurant tables or in markets. On the downside, oysters are not yet commercialized in a standardized packaging and are sold by the unit, dozen, hundred or thousand, according to the client's needs.

Another problem for the oyster culture sector in Pará is in relation to public health and involves the need to establish reliable depuration facilities so that oyster growers can bring their products for sanitation before marketing. Although non-obligatory under Brazilian law, São Paulo and Santa Catarina states have again lead the way in terms of the safety of cultivated oysters by providing depuration facilities, financed by the World Bank in São Paulo. Although raw *Crassostrea gasar* may be micro-biologically safe for consumption for up to 8 days after harvesting (Maziero & Neto 2015). Ristori *et al*. (2007) reported that microbial pathogens were less prevalent in depurated oysters than in non-depurated ones. Gamma irradiation has been used to inactivate *Salmonella* and *Vibrio* microbes in *C. gasar*, without affecting odor, flavor or appearance of the oyster (Jakobi *et al*. 2003). As oyster culture expands along the northern and northeastern coasts of Brazil, so too have records of pathogens and diseases, some of which require notification, such as *Perkinsus spp*., associated with *Crassostrea gasar*, including the estuarine region of the São Franciso in Bahia (Silva *et al*. 2014; Silva *et al.* 2015), the Mamanguapé in Paraíba (Queiroga *et al.* 2015), Cananéia in São Paulo (Ristori *et al*. 2007) and along the coast of Pará state (Azevedo *et al*. 2005). Access to depuration facilities will not only be beneficial for public health, but, along with certification will also increase the value and acceptability of oysters on the market. Unusually, some stall-owners, which sell oysters at beaches, purchase non-depurated oysters, which they say their clients prefer because non-depurated oysters taste better, according to members of the cooperative Cooperostra in Cananéia, São Paulo, in an interview during the present study.

Finally, calcium carbonate from cultivated oyster shells, which are otherwise discarded, could provide raw material for a diverse range of products for construction, cosmetics and other industries (Chierighini *et al.* 2011). Non-organic residues (mainly plastic debris) may pose a problem in coastal areas where oyster culture is intensive (Liu *et al*. 2015). In Pará, the use of natural materials from the mangrove means residues from oyster culture are mostly biodegradable, but of course, the use of materials from the mangrove has a potential negative impact on the habitat, which needs to be mitigated by sustainable management.

Relationships and identification with other institutes and external entities

The associations AGROMAR and AQUAVILA stand apart from the others for having partnerships with more than six institutions. The length of time in the activity is an important factor for establishing partnerships. Institutes of higher education feature significantly in associations carrying out research in the municipalities of Augusto Corrêa (Nova Olinda) and Curuçá (Lauro Sodré), where oyster culture has been carried out over the past 10 years, much longer than in the other areas. Association presidents report a total of fifteen (15) institutions that are partners with the oyster culture sector in Pará, of which SEBRAE/PA and SEPAq are involved with all seven associations (Table 4; Figure 7). It should be noted that mostly all institutes are public, either Federal, State or Municipal and there are very few partnerships with businesses and non-governmental organizations.

Since 2009, SEBRAE/PA, through RNP, has stimulated regular discussion of oyster culture activities in Pará state, which have been very helpful for the sector's development and growth. Institutes of higher education and research took part regularly in these discussions at the start, but the statutes of the Rede Nossa Pérola were changed in 2010 such that IHERs would only be invited to take part in the network on an *ad hoc* basis. The contribution from scientific research to supporting aquaculture in Brazil is sometimes neglected by the sector (Valenti & Moraes-Valenti, 2010). Thus, IHERs in Pará will need to systematically engage the sector more aggressively, securing partnerships with as many associations as possible and by demonstrating a continued and ample participation in the network, try to win back support for their regular inclusion in the network.

One of the advantages of aquaculture in relation to fishing and sea-food harvesting is a much stronger linkage to services and industry as well as a wider socio-economic effect associated with the aquaculture (Byron *et al.* 2014). For example, in France, interaction between oyster culture, heritage and tourism may have potential, once tourist preferences are known (Dachary-Bernard & Rivaud 2013). In Brazil, there is a strong relationship between oyster culture and tourism and general culture, for example, the National Oyster and Azorean Culture Festival (Festa Nacional da Ostra e da Cultura Açoriana), which has taken place annually in Florianópolis, Santa Catarina for the past 15 years (Corrêa & Müller 2016). Although oyster culture has a lower revenue than other industries, this is offset by greater ecological and social sustainability (lower rates of unemployment) (Chen *et al*. 2013) and oyster culture has been seen as a means of reducing poverty and unemployment in coastal communities (Olivier *et al*. 2013) and even where the sector has been recently established, such as in South Australia where oyster growing began at the end of the 1980s, there have been positive benefits for the local community (Pierce & Robinson 2013). Closer interaction between authorities and the oyster culture sector in New South Wales, Australia has created benefits in relation to sustainability and the protection of estuarine habitats (Connor & Dove, 2009). On the one hand, the Australian authorities have been proactive in regard to protecting estuaries where oyster culture is carried out, whereas, on the other, the oyster culture industry has moved to rely on laboratory raised seed, as well as develop environmentally based research in aquaculture. Thus, there are sound social, economic and environmental reasons for the involvement of industry, services and government authorities, as well as the public in general, in supporting oyster culture. This is a situation which will certainly need strengthening in Pará state.

Licensing, environmental legislation and future perspectives

Environmental licensing from public authorities is designed to verify adherence to technical and legal obligations associated with certain activities in order to harmonize economic development with the protection of natural resources (Viana *et al*. 2012). Currently, none of the oyster culture associations active in Pará state have been included in the areas designated as Aquatic Parks Parques Aquícolas by the now extinct MPA. According to SEBRAE/PA, all seven associations are exempt from licensing since each of their cultivable areas is less than one hectare. Oyster growers are now applying for registration with the Federal Government as Aquaculturists. Up to now, none of the associations possess a concession for use of water resources (Outorga da Água) that is granted by the National Waters Agency or Agência Nacional de Águas (ANA).

Conclusions

Since the start of activities in 2006, oyster culture in Pará state has been assisted by government funded projects. The sector has clearly grown in terms of on-growing capacity, production; number of producers and number of associations. Weaknesses in the sector that have emerged in recent years need to be tackled, and include the need for transition to cooperatives, reducing the asymmetry in seed supply, the introduction of legislation for the protection of natural oyster beds, access to secure depuration facilities before sale, solutions to problems of the logistics of transport and packaging, diversification of marketing efforts, adoption of risk perception and management strategies, as well as increasing investments and partnerships with private enterprise and institutes of higher education.

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Table 1 Name, municipality, abbreviation and year of establishment of each of the seven oyster culture associations in Pará state, as well as the total number of active members and the number of interviewees in each association during the present study.

Association, Municipality	Abbreviation	Year established	Total active members, number interviewed
Associação de Mulheres na Pesca e Agricultura de Pererú, São Caetano de Odivelas	AMPAP	2007	13, 8
Associação dos Produtores de Ostras de Pererú de Fátima, São Caetano de Odivelas	ASSOPEF	2006	11; 11
Associação de Aquicultores da Vila de Lauro Sodré, Curuça	AQUAVILA	2006	10; 6
Associação Agropesqueira de Nazaré de Mocajuba, Curuça	AGRONAM	2012	13; 7
Associação dos Aquicultores, Produtores Rurais e Pescadores de Nazaré do Seco, Maracanã	AAPPNS	2006	10; 6
Associação dos Agricultores e Aquicultores de Santo Antônio de Urindeua, Salinópolis	ASAPAQ	2009	9; 5
Associação dos Agricultores e Aquicultores de Nova Olinda*, Augusto Corrêa	AGROMAR	2006	13; 13

*Formerly known as Associação Agropesqueira de Nova Olinda (AGRONOL).

Table 2 Age distribution (years) among oyster growers (n=56) from seven oyster culture associations from Pará state, interviewed in 2013.

Statistic	AMPAP	ASSOPEF	AGRONAM	AQUAVILA	ASAPAQ	AAPNS	AGROMAR
Minimum	25.0	23.0	25.0	26.0	30	35	26
1st Quartile	37.5	31.5	37.0	27.0	47	37	30
Median	44.0	42.0	48.0	35.5	48	42	40
Mean	46.1	41.2	44.7	37.5	51.8	42.8	40.5
3rd Quartile	56.5	44.5	52.5	39.0	63	44	49
Maximum	68.0	60.0	61.0	39.0	71	44	59

Table 3 Numbers of on-growing bags among oyster culture associations in Pará state between 2011 and 2013 (SEBRAE/PA, 2014).

	Year		
Association	**2011**	**2012**	**2013**
AMPAP	72	84	1182
ASSOPEF	118	70	887
AQUAVILA	279	236	1382
AGRONAM	0	100	476
AAPPNS	102	107	903
ASAPAQ	80	90	921
AGROMAR	276	222	1775
Total	**927**	**909**	**7526**

Table 4 Institutions that provide financial, infrastructural support and/or training advice and consultancy to oyster culture associations in Pará state between 2013 and 2014.

	Associations						
Institutions	**AMPAP**	**ASSOPEF**	**AQUAVILA**	**AGRONAM**	**AAPPNS**	**ASAPAQ**	**AGROMAR**
Brazilian Support Service to Micro and Small Enterprises (SEBRAE/PA)	X	X	X	X	X	X	X
State Department of Fisheries and Aquaculture of the State of Pará (SEPAQ)	X	X	X	X	X	X	X
Pará State Enterprise Technical Assistance and Rural Extension (EMATER), Pará.		X	X	X			
University Federal of Pará, Belém		X					X
University Federal of Pará, Bragança				X			
Federal Institute of Pará/Castanhal						X	
Federal Institute of Pará, Bragança				X			
Prefecture, Augusto Corrêa				X			
Prefecture, Curuçá			X				
Prefecture, Salinópolis						X	
Ministry of Fisheries and Aquaculture (MPA)*, Brasília				X		X	
Workers Union, Curuçá			X				
Fishing Union Z-05, Curuçá			X				

*Institutions dissolved in 2015.

Figure legends

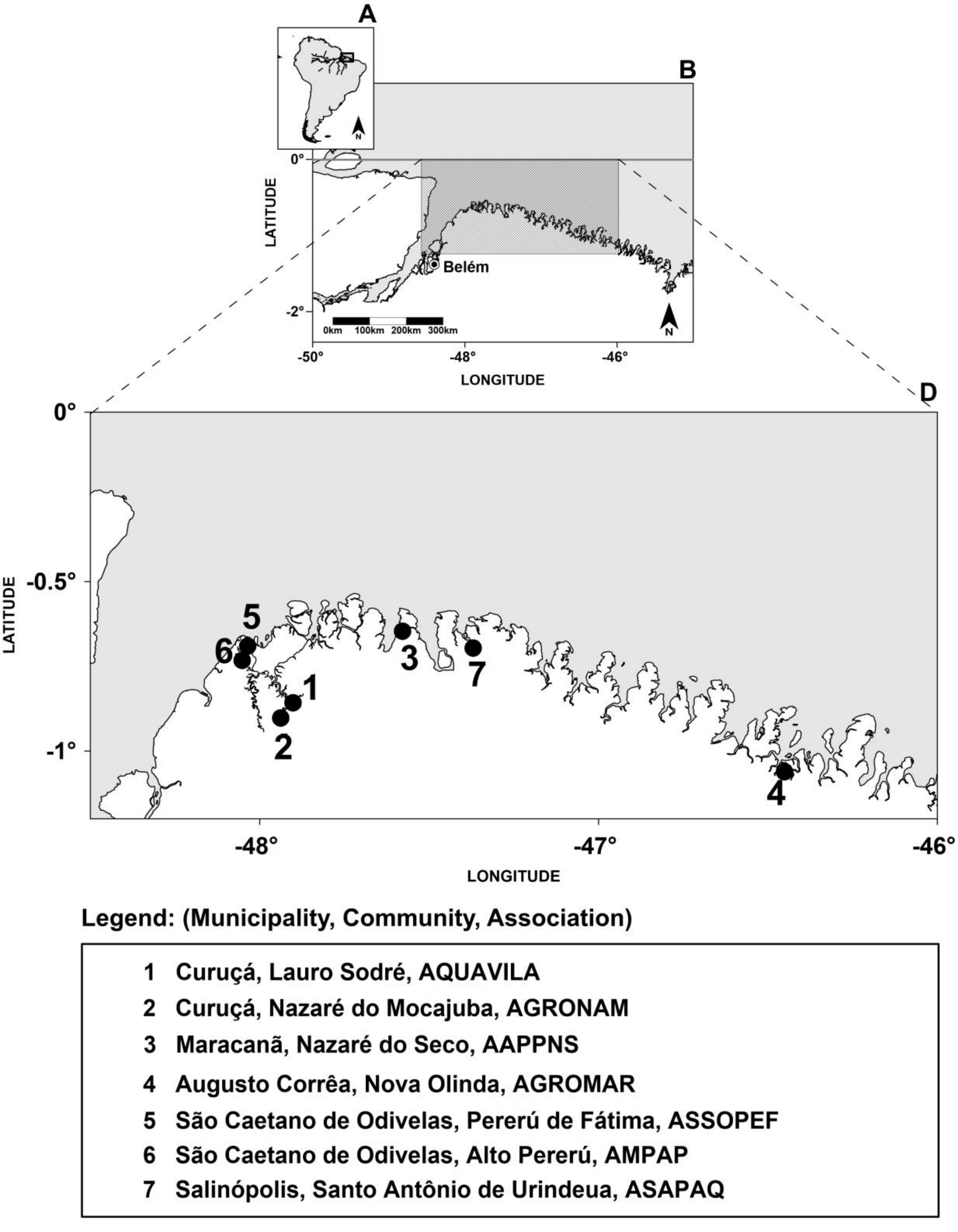

Figure 1 Location, on the northern coast of South America (A), of the study area, along the northeastern coast of Pará state (D), and the seven oyster culture associations (C: 1-7).

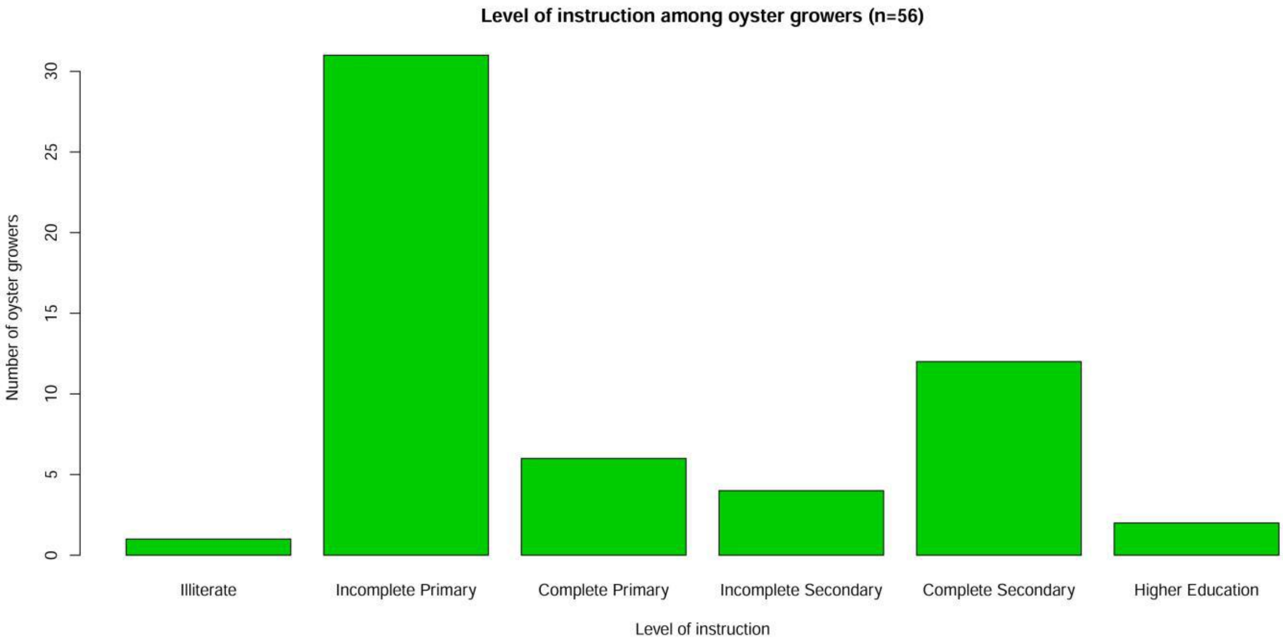

Figure 2 Level of instruction among oyster growers (n=56) from seven oyster culture associations from Pará state, interviewed in 2013.

Figure 3 Oyster farming in the community of Nova Olinda, Municipality of Augusto Corrêa, with both oyster on-growing systems (fixed system and floating system). Photograph by lead author. Fonte: http://www.worldoyster.org/oysterfarm/oysterfarm_photo_e/bra13.html

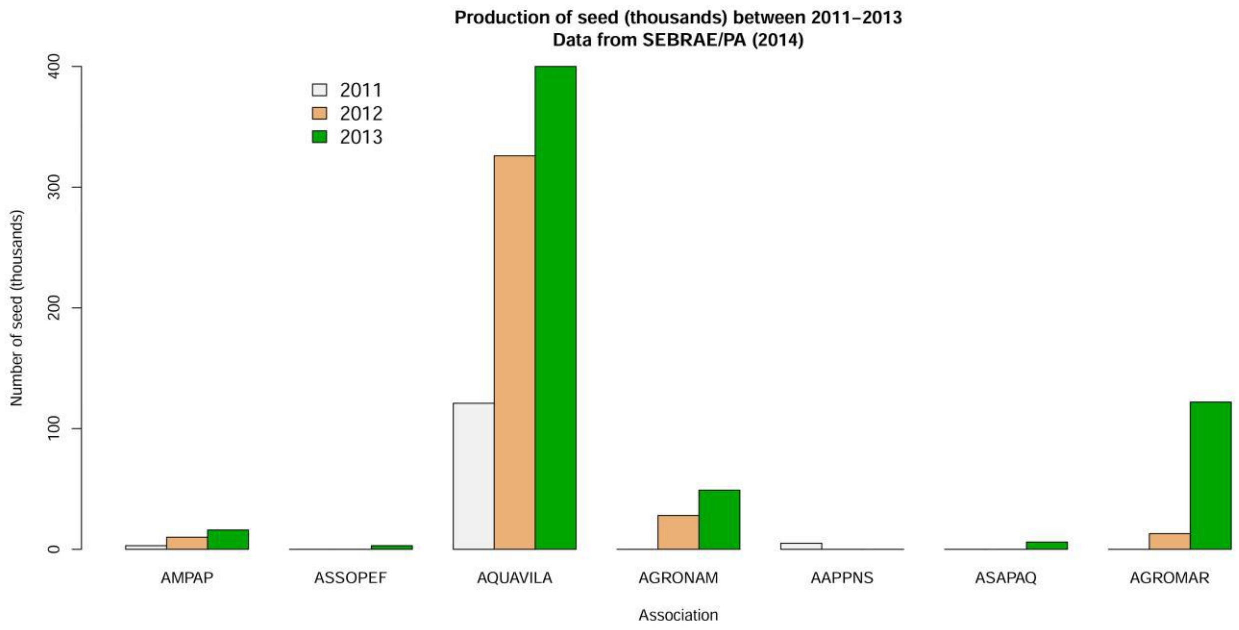

Figure 4 Number of seed (in thousands, or *milheiro*) acquired by oyster culture associations in Pará between 2011 and 2013 (SEBRAE/PA, 2014). Up to recently, AQUAVILA was the only producer of seed, which is harvested from the wild and sold to the other associations.

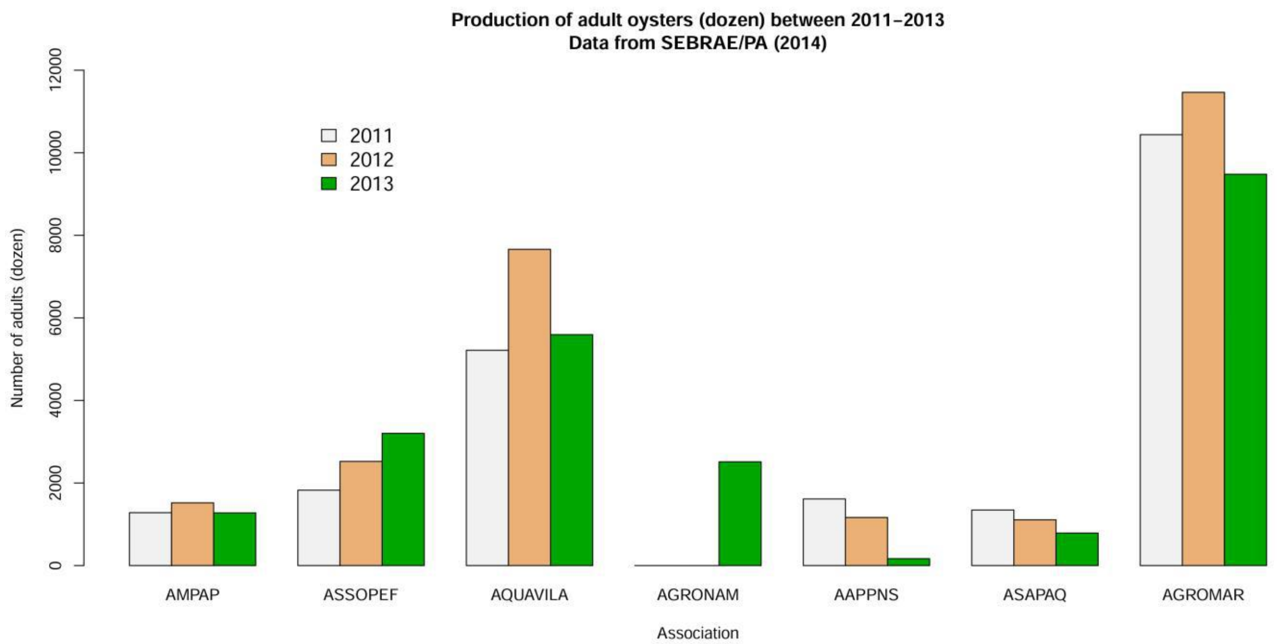

Figure 5 Total production of adult oysters (in numbers of dozens) sold by oyster culture associations in Pará between 2011 and 2013 (data from SEBRAE/PA 2014).

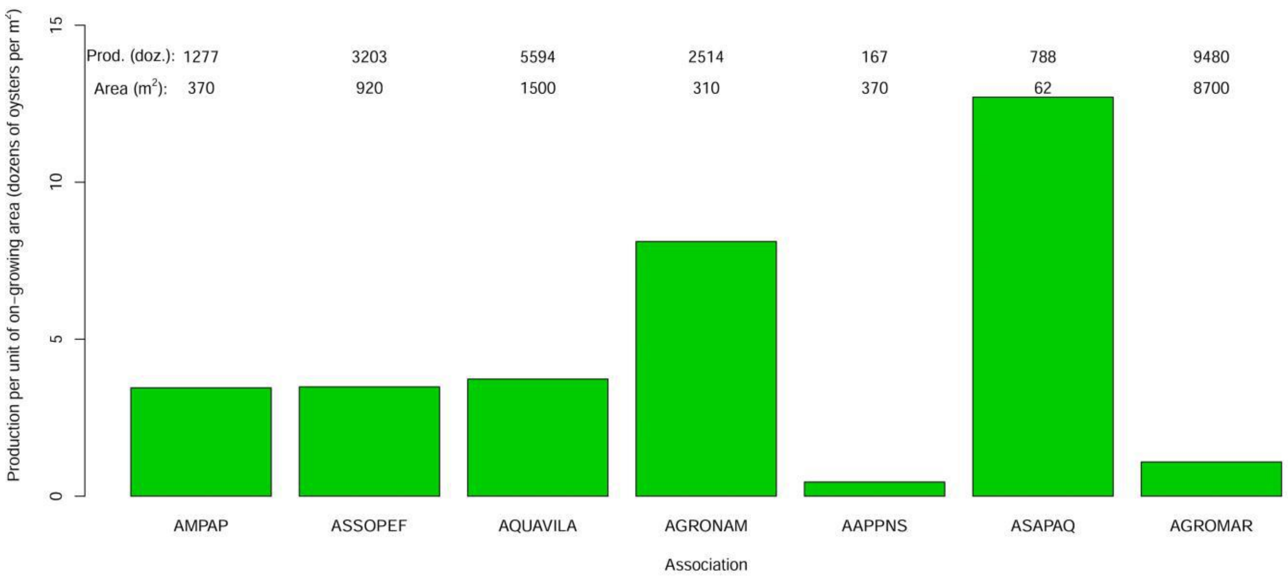

Figure 6 Total oyster production (data from SEBRAE/PA 2014) per unit of on-growing area (dozen per m²) at each of the seven oyster culture associations in Pará in 2013. Total production of oysters (dozen) and area (m²) are given above each bar.

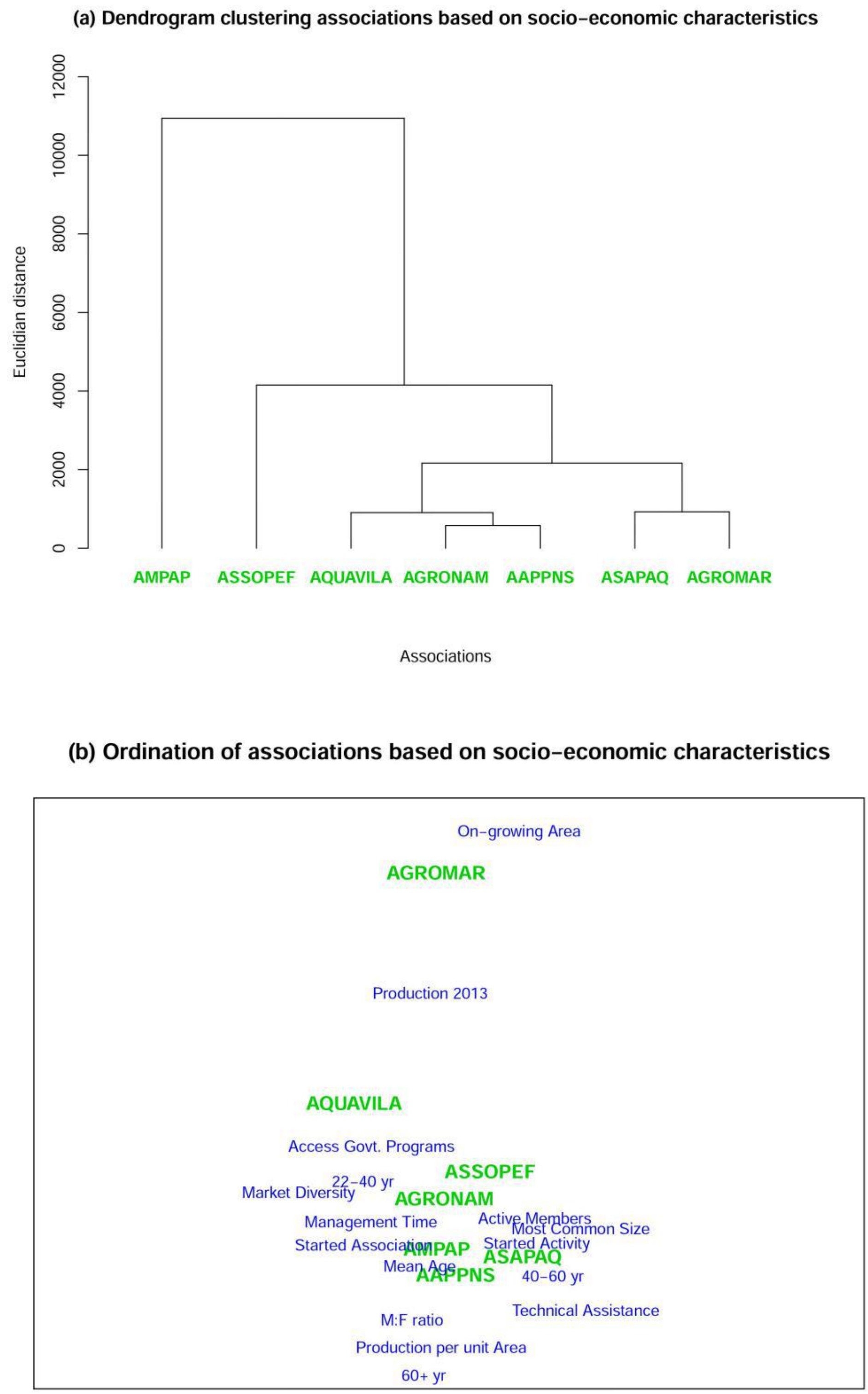

Figure 7 Hierarchical agglomerative clustering (a) and non-metric multidimensional scaling (b) of the seven oyster culture associations using a Euclidean distance matrix based on socio-economic characteristics (See text for details).

CAPÍTULO 2

Physical-chemical characteristics of the water at oyster culture units on the Amazon macrotidal mangrove coast of northern Brazil*.

DIONISO S. SAMPAIO

MARIA L. S. SANTOS

CLAÚDIA HELENA TAGLIARO

COLIN ROBERT BEASLEY

* Submetido ao periódico científico

ACTA AMAZONICA (QUALIS B2) – BIODIVERSIDADE

(ANEXO 02)

Physical-chemical characteristics of the water at oyster culture units on the Amazon macrotidal mangrove coast of northern Brazil

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Running Head: Amazon mangrove oyster culture water

ABSTRACT

Along the Amazon macrotidal mangrove coast, oyster culture is generating revenue and opportunities for communities and associations, as well as employment directly or indirectly through associated services. In the state of Pará, oyster culture has been carried out since 2006, and currently takes place at seven associations in five municipalities. The present study investigated physical-chemical characteristics of the water at all oyster culture units in Pará. Salinity, temperature (ºC), oxidation-reduction potential (mV), pH, dissolved oxygen ($mg.l^{-1}$) and chlorophyll-*a* concentration ($mg.m^3$) were measured *in situ* using a digital probe in both the dry season of 2013 and the rainy season of 2014. All variables, except depth, were significantly greater in the dry season. Mean salinity, which varied from 2.4 to 46, is the single most important variable explaining variation among associations in relation to season, sampling date within each season and tidal state. However, dissolved oxygen, pH and depth were also important. Oyster culture units in Pará may be defined in terms of water quality as being suitable for harvesting seed/spat from the wild, or for on-growing (higher salinity, higher pH, and greater depth).

KEYWORDS: tropical mariculture, oyster, water quality and *Crassostrea*.

RESUMO

Ao longo da costa de manguezal de macromarés da Amazônia, a cultura da ostra está gerando receita e oportunidades para comunidades e associações, bem como o emprego direto ou indireto através de serviços associados. No estado do Pará, a cultura da ostra tem sido realizada desde 2006 e atualmente ocorre em sete associações em cinco municípios. O presente estudo investigou as características físico-químicas da água em todas as unidades de cultivo de ostra no Pará. Salinidade, temperatura (ºC), potencial de oxidação-redução (mV), pH, oxigênio dissolvido ($mg.l^{-1}$) e a concentração de clorofila-*a* ($mg.m^3$) foram medidos *in situ* usando uma sonda digital tanto na estação seca de 2013 quanto na estação chuvosa de 2014. Todas as variáveis, exceto a profundidade, foram significativamente maiores na estação seca. A salinidade média, que variou de 2,4 a 46, é a variável mais importante que explica a variação entre associações em relação à estação, data de amostragem em cada estação e estado da maré. No entanto, o oxigênio dissolvido, pH e profundidade também foram importantes. As unidades de cultivo de ostra no Pará podem ser definidas em termos de qualidade da água como adequadas para a colheita de sementes da natureza (menor salinidade e pH, ou para o cultivo de adultos (maiores valores de salinidade, pH e profundidade).

PALAVRAS-CHAVES: maricultura tropical, ostra, *Crassostrea* e qualidade da água.

INTRODUCTION

The Amazon Macrotidal Mangrove Coast (AMCC) of northern Brazil extends from Marajó Bay, Pará state to São José Bay, Maranhão state (Nascimento-Jr *et al*. 2012) with a series of estuaries forming a highly indented coastline (Dominguez, 2009) dominated by mangrove forest (Souza-Filho *et al*. 2006; Saint-Paul and Schneider 2010). This mangrove coast is the most conserved in all of Brazil and one of the longest continuous mangrove forests in the world (Nascimento-Jr *et al*. 2012).

The native mangrove oyster, *Crassostrea gasar*, is the predominant species found along the AMCC (Varela *et al*. 2007; Melo *et al*. 2010) and, since 2006, has been cultivated along the eastern sector of the Pará state coast in the municipalities of Augusto Corrêa, Salinópolis, Maracanã, Curuçá and São Caetano de Odivelas with the support of the *Serviço Brasileiro de Apoio à Pequena e Microempresa* (SEBRAE/PA) and other institutions involved in teaching, research, outreach and funding (Sampaio and Boulhosa 2007; Hoshino, 2009). The AQUAVILA unit in Curuça is recognized as the only one in Brazil where oyster seed is harvested from the wild for commercial sale to other units (IBGE, 2014). A second unit, AGRONAM in Nazaré de Mocajuba, Curuçá, began commercial harvesting and sale of wild seed in 2016 but at a much smaller scale than AQUAVILA (D. Sampaio, pers. obs.).

The macrotidal mangrove coast is strongly influenced by seasonal freshwater influx from the Amazon and other rivers, as well as by semidiurnal macrotides with amplitudes of 4 to 7 m (Silva *et al.* 2011). Both seasonal freshwater influx and tidal variation, as well as mangrove vegetation and sediments, influence salinity, nutrients and productivity of the Amazon shelf coastal waters (Dittmar and Lara 2001; Berrêdo *et. al.* 2008; Santos *et al*. 2008a, 2008b; Rosario *et al.* 2009; Pamplona *et al.* 2013). The duration of the rainy season and the volume of rainfall varies from east to west along the Pará coast (Moraes *et al*. 2005) associated with seasonal and geographic variation in salinity (Braga *et al.* 2013). In coastal waters around Marajó island, close to the mouth of the Amazon, salinity is consistently less than 10 during the wet season (Santos *et al.* 2008a) and varies from 0 to 7.6 on the eastern side of Marajó where there is a freshwater influence from the Pará and Tocantins rivers (Alves *et al.* 2012; Monteiro *et al.* 2015). Thus, oyster culture in Pará is restricted to seven units located further east along the coast where salinity ranges from 5 to 35 (Saint-Paul and Schneider 2010).

Data from estuaries along the Pará coast show that temperature, pH, salinity, chlorophyll-*a*, as well as concentrations of gases and nutrients in mangrove coastal waters, vary considerably among estuaries and between the wet and dry seasons (Berrêdo *et al*. 2008; Pereira *et al*. 2010; Alves *et al*. 2012; Vilhena, 2014; Asp *et al.* 2013; Pamplona *et al.*, 2013; Monteiro *et al*. 2015; Moura and Nunes 2016; Monteiro *et al.* 2016). For example, surface water salinity varies from 1 to 35 at Marapanim (Berrdo *et al*. 2009), 0 to 40 in the Caeté (Monteiro *et al*. 2016), <10 to 40 in the Taperaçu estuary (Costa *et al*. 2016). Knowledge of this variation is important for oyster culture since larval settlement (Nascimento, 1991), and both juvenile and adult survival and growth (Lopes *et al*. 2013; Funo *et al.* 2015), are associated with physical-chemical characteristics of the water, such as, temperature (Lemos *et al.* 1994; Devakie and Ali 2000; Heilmayer *et al*. 2008; Christo and Absher 2006), salinity (Devakie and Ali 2000; Heilmayer *et al*. 2008; Dickinson *et al*. 2012; Funo *et al*. 2015), pH (Gireesh and Gopinathan 2004), carbon dioxide (Dickinson *et al*. 2012), and concentrations of microalgas (Devakie and Ali 2000; Ramos *et al*. 2013). In oyster culture, estuarine salinity, an important factor with implications for commercial production (Funo *et al*. 2015), may vary daily or seasonally, due to tidal regime and rains, respectively (Dittmar and Lara 2001; Asp *et al.*, 2013; Pamplona *et al.*, 2013; Monteiro *et al*. 2016). The effects of salinity have been investigated in different oyster species (Ramos and Castro 2004; Bergquist *et al*. 2006; Dove and O`Connor 2009; Betanzos-Vega *et al*. 2014; Figueiredo 2015; Funo *et al*. 2015).

The native mangrove oyster *Crassostrea gasar* has been important for generating income and employment for traditional communities, as well as for associated services, along the eastern Pará coast over the past decade (Sebrae, 2010; França *et al.* 2011; Macedo *et al.* 2016). However, there is no environmental monitoring of waters around the culture units and increasing coastal development is a threat to oyster diversity and stocks (Carranza *et al*. 2009). Little is known of the variation in water chemistry at oyster culture units along the northeastern Pará coast. Thus, the aim of the present study was to determine the variation in physical-chemical variables of the mangrove estuary water at all 7 oyster culture units along the eastern sector of the Pará coast during the dry season between September and November 2013 and during the wet season between February and April 2014.

MATERIAL AND METHODS

Study Area

The study covers the so-called northeast coast of Pará state, which represents 6.7% (83,182.6 km^2) of the total area of Pará, and a population of 1.473 million inhabitants, or 23.8% of the state population. (IBGE, 2011). Surveys were carried out in each of the seven oyster culture associations in five municipalities in the region: Associação dos Agricultores e Aquicultores de Nova Olinda (AGROMAR), formerly Associação Agropesqueira de Nova Olinda (AGRONOL) in the municipality of Augusto Corrêa, Associação dos Aquicultores, Produtores Rurais e Pescadores de Nazaré do Seco (AAPPNS) in the municipality of Maracanã, Associação de Aquicultores da Vila de Lauro Sodré (AQUAVILA) and Associação Agropesqueira de Nazaré de Mocajuba (AGRONAM) in the municipality of Curuçá, Associação dos Agricultores e Aquicultores de Santo Antônio de Urindeua

(ASAPAQ) in the municipality de Salinópolis, Associação de Mulheres na Pesca e Agricultura de Pererú (AMPAP) and the Associação dos Produtores de Ostras de Pererú de Fátima (ASSOPEF) in the municipality of São Caetano de Odivelas.

Data collection in the field

Fieldwork took place between September and November 2013 and between February and April 2014, periods chosen on the basis of monthly accumulated rainfall (mm) at automatic weather stations belonging to the *Instituto Nacional de Meteorologia* (INMET) in northeastern Pará (A202 Castanhal, A215 Salinópolis and A226 Bragança), and the definition of the regional dry and wet seasons, based on long term (30 year) rainfall data (Moraes *et al.* 2005).

In each period mentioned above, all seven oyster culture associations were visited during the flooding and/or ebbing tide, during the full or new moon. Data were recorded on three occasions at the beginning, middle and end of each tidal phase (flooding or ebbing) in each of three equidistant areas at each culture unit. Thus, sampling in each of 3 months (September to November and February to April) with n=3 tidal replicas and n=3 culture unit area replicas resulted in N=27 replicas for each of the 7 associations in each of 2 seasons (Dry, Wet), generating a grand total of 378 observations.

Salinity, temperature (^{o}C), oxidation-reduction potential (mV), pH and dissolved oxygen ($mg.l^{-1}$) were measured *in situ* with a digital probe (HANNA HI-9828). Depth (m) was measured with a digital echo sounder (Speedtech SM5). Chlorophyll-*a* concentration ($mg.m^{-3}$) was determined 36 hours after transport of refrigerated water samples to the laboratory, according to the method of Teixeira (1973), based on extraction of pigments with 90% acetone.

Data treatment and analysis

All data were analyzed using GNU R version 3.3.3 (R Core Team, 2017). Differences in mean values of each variable among associations in each season were verified using Analysis of Variance (ANOVA), with Tukey's Honestly Significant Difference *post-hoc* comparison of pairwise differences, wherever a significant group difference was found. Posterior diagnostic analysis of residuals was used to verify if ANOVA assumptions of residual normality and homogeneity were met. Otherwise, ANOVA was rerun on appropriately transformed observations. Data for each variable were presented as box-plots with overlaid mean and standard error bars, as well as raw observations for each association in both the dry and wet seasons.

Multivariate ordination of replicas from each association in each season was carried out using non-metric multidimensional scaling (MDS) on a distance matrix calculated using euclidean distance from the physical-chemical variables using the *metaMDS* function in the package *vegan* (Oksanen *et al*. 2017). The physical-chemical variables significantly associated with the pattern of dispersion of replicas in the MDS ordination were selected using the *envfit* function, also in *vegan*. Multivariate differences in the physical-chemical characteristics among associations, sampling date (month) and tide (flooding, ebbing) were tested for using multivariate permutational analysis of variance (Permanova), using the function *adonis* in *vegan*.

RESULTS

For all variables, there were very clear and significant seasonal differences between the dry (October-November 2013) and wet (February-April 2014) seasons (Table 1). Salinity, temperature, oxidation-reduction potential, pH, dissolved oxygen and chlorophyll-*a* measured in November 2013 and April 2014, all decreased significantly from the dry to the wet season, whereas depth increased (Figures 1a-g).

During the dry season, significant differences in mean values of salinity, temperature, pH, depth and dissolved oxygen, as well as chlorophyll-*a* measured in November 2013, were found among oyster culture units (Table 1). In the wet season, significant differences in mean values of salinity, temperature, oxidation-reduction potential, pH, depth and dissolved oxygen, as well as chlorophyll-*a* measured in April 2014, were found among oyster culture units (Table 1).

Mean salinity was significantly higher in the dry season (Figure 1a, Table 1). Among associations in the dry season, mean salinity was lowest at AGRONAM (11.5) and AQUAVILA (22.7), both in Curuça and with high freshwater input from the Mocajuba river, followed by AMPAP and ASSOPEF, and was highest (above 40) at AAPNS, ASAPAQ and AGROMAR, further east (Figure 2a). In contrast, in the wet season, mean salinity was similar (2.4 - 8.1) at all associations, except AGROMAR (13.9). Seasonal differences were large at all sites except AGRONAM and AQUAVILA, resulting in significant interaction between season and association (Figure 1a, Table 1).

Mean temperature was significantly higher in the dry season (Figure b, Table 1) during which temperature was lowest at AGRONAM (28.4 ^{o}C) and AGROMAR (28.8 ^{o}C) and was slightly higher (29.0 - 29.8 ^{o}C) at the other associations (Figure b). In the wet season, mean temperature was lowest at ASAPAQ (26.8 ^{o}C), intermediate at AMPAP, ASSOPEF and

AGRONAM (27.4 - 27.8 ^{o}C), and highest at AQUAVILA, AAPNS and AGROMAR (27.9 - 28.2 ^{o}C). Seasonal differences in temperature were lowest at AGRONAM, AAPNS and AGROMAR, but were much greater at the other sites, especially ASAPAQ, leading to significant interaction (Figure 1b, Table 1).

Mean oxidation-reduction potential were always negative and differed significantly between seasons but did not among associations, nor was there significant interaction (Figure 1c, Table 1). However, the probability that the association means were similar was only 6% (Table 1). Mean values ranged between -100.1 to -123.7 mV in the dry season and between -144.7 to -175.4 mV in the wet season (Figure 2c) with a tendency to increase from west to east, especially in the dry season.

Mean pH was significantly higher in the dry season (Figure 1d, Table 1). Variation in mean values of pH was remarkably similar among associations in each season (Figure 1d), despite the significant interaction term (Table 1), which was due to very low seasonal variation at AAPNS in relation to the other associations. In both seasons, mean pH values were lowest at AGRONAM and AQUAVILA, varying from 6.7 to 6.9 and 7.4 to 7.6 in the dry and wet season, respectively (Figure 1d). Variation at other associations ranged from 7.9 to 8.3, and 7.1 to 7.9, in the dry and wet season, respectively (Figure 1d).

Mean depth was significantly greater in the wet season (Figure 1e, Table 1). Variation in mean depth among associations was remarkably similar in each season (Figure 1e), although interaction was significant (Table 1), due to the low seasonal difference at AQUAVILA in relation to the other associations. In both seasons, mean depth was lowest and relatively similar at ASSOPEF, AGRONAM, AQUAVILA and AAPPNS (2.5 - 3.4 m), slightly greater at AMPAP and ASAPAQ (3.2 - 3.8 m), and highest at AGROMAR (4.6 - 5.0 m) (Figure 1e).

Dissolved oxygen was significantly higher in the dry season and varied widely among associations, ranging from 1.8 $mg.l^{-1}$ at AQUAVILA to 4.2 $mg.l^{-1}$ at AAPPNS (Figure 1f, Table 1). Mean values were intermediate (2.1 - 3.0 $mg.l^{-1}$) at the other associations. In the wet season, mean dissolved oxygen concentrations were low but similar at most associations (0.4 - 1.6 $mg.l^{-1}$) and highest at AGROMAR (2.0 $mg.l^{-1}$). There was significant interaction (Table 1) due to very low seasonal differences at AQUAVILA and AGROMAR, and very large differences at AAPPNS and ASAPAQ in relation to the other associations (Figure 1f).

Mean values of chlorophyll-*a* were significantly higher in November 2013 (end of dry season) than in April 2014 (end of wet season) (Figure 1g, Table 1). Mean chlorophyll-*a* values were similar ranging between 2.2 and 3.0 $mg.m^{-3}$ among associations in November 2013, with the exception of AGRONAM where there was an exceptionally high mean value of 6.96 $mg.m^{-3}$. In the wet season, mean chlorophyll-*a* values were very low (<0.6 $mg.m^{-3}$) at all associations, except at AQUAVILA (1.4 $mg.m^{-3}$) (Figure 1g).

In the dry season, the greatest significant multivariate differences in physical-chemical characteristics of the water, based on F and r^2 values, were found among associations (Table 2). All physical-chemical variables were significantly associated with the multivariate scaling of replicas (Figure 3a, Table 3), the stress of which was 2.09%, indicating an excellent 2-dimensional representation of the data. Salinity (r^2=0.9999), dissolved oxygen (r^2=0.8512) and pH (r^2=0.5337) explain the greatest amount of variation among the replicas, which was associated with the west to east geographic location of the associations along a gradient of increasing salinity from the less saline associations at AGRONAM and AQUAVILA, through intermediate salinities at AMPAP and ASSOPEF to the more easterly high salinity associations of AAPNS, ASAPAQ and AGROMAR (Figure 3d, See Figure 1 for geographic location of associations). In relation to sampling date (month) in the dry season, there were also smaller but significant multivariate differences (Table 2), as shown by a gradient in terms of temperature, which increases from September to November, associated with decreases in dissolved oxygen concentration, pH and depth (Figure 2b). Tidal state in the dry season was not associated with any of the variables or the spatial configuration of replicas in the ordination (Figure 2c) and there was no significant multivariate difference related to tidal state (Table 2). Dissolved oxygen concentrations clearly decrease from September to November (Figure 2e). Although pH values tend to be higher in September and October, there is wide variation in these months and values are also high in November at AGROMAR (Figure 2f).

In the wet season, the greatest significant multivariate differences in physical-chemical characteristics of the water, based on F and r^2 values, were found among sampling dates (months) (Table 2). All physical-chemical variables were significantly associated with the multivariate scaling of replicas (Figure 3a and Table 3), the stress of which was 4.02%, indicating an excellent 2-dimensional representation of the data. Salinity (r^2=0.9984) and depth (r^2=0.8914), and to a lesser degree, dissolved oxygen (r^2=0.4564) and pH (r^2=0.3465), explain the greatest amount of variation among the replicas, which was again strongly associated with a gradient of increasing salinity. However, there was more variation in salinity within associations during the wet season. In general, the associations with lowest salinity were AGRONAM, ASAPAQ, AQUAVILA, AMPAP and ASSOPEF, through intermediate salinity at AAPNS to high salinity at the most easterly association AGROMAR (Figure 3a, See Figure 1 for geographic location of associations). In relation to sampling date (month) in the dry season, there were larger significant multivariate differences (Table 2), with April being distinct from February and March (Figure 3b). Greater depth was associated with replicas from AGROMAR in February, higher dissolved oxygen concentration with replicas from AAPNS in March and April and greater pH with replicas from AAPNS in March (Figure 3a).

Although there were significant multivariate differences related to tidal state in the wet season, these were weak effects (r^2=0.03) (Figure 3c, Table 2). The gradient in salinity, which increases from February-March to April (Figure 3d), explains the wide temporal variation within some associations such as AAPNS, AMPAP, ASSOPEF, AQUAVILA and AGROMAR, which had higher salinities in April in comparison to ASAPAQ and AGRONAM (Figure 4a and Figure d). Flood tides in March and April tend to be associated with higher salinity and greater depth, especially at the most easterly associations, such as AAPPNS and AGROMAR (Figure 4d and Figure 4e). However, flood tides, especially in March and April, are clearly associated with higher dissolved oxygen concentrations (Figure 3f).

DISCUSSION

The Amazon mangrove macrotidal coast estuaries are relatively shallow and are thus well mixed in relation to water chemistry and suspended solids due to tides, freshwater input and winds (Berrêdo *et al*. 2008; Asp *et al*. 2013; Pamplona *et al.* 2013; Monteiro *et al*. 2015). In the wet season, terrestrial and riverine runoff influence estuarine water quality and the distribution of nutrients and particulate matter (Dittmar and Lara 2001; Asp *et al*. 2013; Monteiro *et al*. 2016). As a result, at oyster culture units along the macrotidal mangrove coast of Pará, salinity, temperature, pH, redox potential, dissolved oxygen, and chlorophyll-*a* are lower in the wet season. The greater nutrient concentrations from wet season terrestrial and riverine runoff (Pamplona *et al*. 2013; Monteiro *et al*. 2015) should favor higher primary production, but increased turbidity in the wet season (Monteiro *et al*. 2015) may reduce primary production. Higher chlorophyll-*a* concentrations in the wet season may reflect resuspended benthic algae (Pamplona *et al.* 2013). In the dry season, coastal waters have a greater influence on estuarine water quality, and, at the oyster culture units in the present study, is characterized by higher salinity, temperature, pH, redox potential, and dissolved oxygen concentrations.

Along the coast of the municipalities of Icatu, Primeira Cruz and Humberto de Campos, in Maranhão state, salinity varied between 5 and 37, and wild native oyster beds (*C. gasar* and *C. rhizophorae*) are more common where annual variation in salinity ranges between 10 and 30 (Funo *et al.* 2015). At oyster culture sites in the Paquatiua estuary, Alcântara, Maranhão, mean salinity reached 36.4 in the dry season and dropped to 15.3 in the wet season (Ramos and Castro, 2004). At Cananéia, São Paulo, salinity varied from 0.2 in November in Itapitangui to 25.2 in August at the Cooperostra unit (Mignani *et al*. 2013). Adult *Crassostrea gigas* tolerate wide variation in salinity (0 - 42.5) for only short periods (Barnes *et al.* 2007). At oyster culture units in Pará, seasonal variation in salinity ranged widely (<10 to >40) due to the greater freshwater runoff between February and April, than that reported above. Variation in salinity in mangrove tidal channels and estuaries may vary considerably during a single tidal cycle (Asp *et al.* 2012; Asp *et al.* 2013). Salinity values were lowest at the AGRONAM and AQUAVILA units due to the influence of freshwater from the Mocajuba river, in the estuary of which Vilhena (2014) recorded salinities between 0 and 18. Salinity in the Marapanim river estuary varied from 2.5 in the wet season through 10, up to 29 in the dry season (Berrêdo *et al*. 2008). Salinities below 10 have been found at culture units in diverse locations (Lopes *et al.* 2013; Mignani *et al.* 2013), but values above 40 have only been found at culture units in northern and northeastern Brazil (Ramos and Castro 2004; Funo *et. al.* 2015) where there is a marked dry season with very low rainfall and high rates of estuarine evaporation (Berrêdo *et al*. 2008), which is especially the case in eastern Pará state (AAPNS, ASAPAQ and AGROMAR), and neighboring Maranhão state (Funo *et al*. 2015). One of the more freshwater units (salinity: mean±standard deviation wet season 8.1±6.8 and dry season 22.7±4.0) in western Pará, AQUAVILA, is the major supplier of wild-harvested seed in Pará and relatively low salinities, of around 25, have been associated with enhanced survival and growth of larval *C. gasar* in the laboratory (Funo *et al*. 2015). On Marajó Island, which is surrounded by the Amazon in the West, and the Pará and Tocantins rivers in the South and East, variation between the wet and dry seasons in estuarine salinity was between 0 and 7.6 in the Paracuarí (Monteiro *et al.* 2015) and zero in the Ararí (Alves *et al.* 2012), both on the eastern coast of the island. In Brazilian mangroves, the abundance of seed of *C. rhizophorae* and *C. gasar* declines at salinities below 19 and 25, respectively (Nascimento, 1991) although *C. gasar* larvae from West Africa may tolerate salinities between 0 and 25 (Sandison, 1966; Afinowi, 1984; Ansa and Bashir 2007). In wild adult populations, *Crassostrea brasiliana* (= *C. gasar*) from Cananéia, São Paulo appears to tolerate well salinities between 8 and 34 (Pereira *et al*. 1988; Pereira and Chagas-Soares, 1996) but develops growth best between 15 and 25 (Nascimento, 1991). In Nigeria, greatest growth and survival of *C. gasar* were found where salinity varied between 15 and 32 (Ajana, 1980; Lopes *et al*. 2013) observed that although *C. gasar* grew well in coastal (mean±standard deviation salinity 33.6 ± 1.6), growth was slightly better in estuarine waters (mean±standard deviation salinity 29.2 ± 2.6) after 11 months in São Francisco do Sul and Florianópolis in the southern state of Santa Catarina.

Water surface temperature varied from 17.0 ^{o}C in August to 28.4 ^{o}C in February, among oyster culture units in Cananéia, São Paulo (Mignani *et al*., 2013). In Pará, the range of variation in temperature was low among culture units and greater between seasons (average seasonal difference 1.4 ^{o}C). Similar values were found at oyster culture units in estuarine areas of São Paulo (Machado et al. 2000; Mignani *et al*. 2013), Santa Catarina (Lopes *et al.*

2013) and Pará (Antunes *et al.* 2013; Macedo *et al.* 2016) states. Temperature in the Marapanim river estuary varied between 27 and 30 ^{o}C, increasing in the dry season, similar to our study. At Marajó island, temperature varied between 28.2 and 29.2 in the Paracauarí estuary and between The abundance and survival of larvae of *C. rhizophorae* and *C. gasar* have been found to be greater at higher water temperatures (Lemos *et al*. 1994; Christo and Absher 2006) and greater spatfall of *Crassostrea* has been recorded in the dry season in the mangrove tidal channels of the Caeté estuary (Beasley *et al*. 2010). In contrast, in the Quatipuru estuary, mean temperature was lower, 29.7 ^{o}C, in the wet season than the dry season, 28.7 ^{o}C, (Pamplona *et al*. 2013).

Dissolved oxygen concentrations are lower and varied less in the wet season than in the dry season, associated with a more negative redox potential. A similar seasonal pattern in dissolved oxygen concentrations was found in tidal channels of the Caeté estuary, Bragança (Moura and Nunes 2016) and at oyster-culture units in Maranhão state (Ramos and Castro 2004), although mean values in the latter studies were higher than those of the present study. At the freshwater dominated Marajó Island, dissolved oxygen was lower in the wet season and varied annually from 2.35 to 6.55 mg.l^{-1} (Monteiro *et al*. 2015). In the Quatipuru estuary, Quatipuru, mean dissolved oxygen concentration was around 4.00 mg.l^{-1} in both the wet and dry seasons, but could reach up to 10.00 mg.l^{-1} in the dry season (Pamplona *et al.* 2013). Lower values of dissolved oxygen in the wet season may be the result of lower photosynthetic activity at this time Antunes *et al*. (2013) and Pamplona *et al*. (2013) found that dissolved oxygen and chlorophyll-*a* concentrations were correlated in the Quatipuru estuary.

Chlorophyll-*a* concentrations were much lower (<2.00 mg.m^{-3}) in the wet season, when turbidity is often high due to terrestrial and freshwater runoff (Dittmar and Lara 2001; Alves *et al*. 2012; Monteiro *et al*. 2015), which may limit phytoplankton productivity. A very similar pattern in chlorophyll-*a* values were recorded at oyster culture sites in Maranhão where mean values were less than 2.0 mg.m^{-3} during the dry season and were between 1.6 and 4.0 mg.m^{-3} during the wet season (Ramos and Castro 2004). In contrast, higher concentrations of chlorophyll-*a* were found in the wet season in two mangrove tidal channels with contrasting salinities on the Ajuruteua Peninsula, Bragança (Antunes *et. al*. 2013; Moura and Nunes 2016) and at estuaries in Marajó Island (Alves *et al*., 2012). In the Caeté estuary, Bragança, (Monteiro *et. al*. 2016) and in the Quatipuru estuary (Pamplona *et al*. 2013) there were no clear seasonal patterns in chlorophyll-*a* concentrations due to high intra-seasonal variation, as a result of variation in terrestrial and freshwater runoff in the wet season and tidal influence in the dry season. However, there is no oyster-culture activity at any of the sites included in the latter studies, and the contrast in the seasonal difference in chlorophyll-*a* concentrations at oyster culture units in Pará and Maranhão with other estuarine studies is striking and may involve the rather more upstream location of oyster culture units. Pamplona *et al*. (2013) note that displacement further downstream of zones of chlorophyll-*a* maxima occur with tidal movements and seasonal freshwater input and that higher values of chlorophyll-*a* may occur in the wet season, despite high turbidity due to resuspension of benthic microphytobenthos. Oyster culture units AGROMAR (Emboraí river) and ASAPAQ (Urindeua river), which had the highest production of adults in 2015 (IBGE, 2016), as well as ASSOPEF and AMPAP, both on the Pererú river, are located in the middle estuarine sectors. AQUAVILA and AGRONAM, where spat harvesting dominate are located in the upper estuarine sector of the Iririteua and Mocajuba rivers, respectively. Only a single oyster culture unit in Pará, AAPNS on the Marapanim river, is located in a lower estuarine sector. The upper and middle estuarine sectors, where mst oyster culture in Pará takes place, may be locations where there is less benthic algal resuspension or that oyster filtering activity reduces chlorophyll-*a* concentrations at these locations.

In the present study, mean pH varied from 6.69 to 8.31. In Maranhão state, mean pH at oystercultre units varied from 6.82 to 8.16 and, similar to our finding, was lower in the wet season (Ramos and Castro 2004). Variation in pH among oyster culture units in Cananéia, São Paulo was between 5.89 and 8.26 (Mignani *et al*. 2013). Values of pH were lower in the wet season, similar to other studies in the region (Alves *et al*. 2012; Monteiro *et al*. 2015). In the present study, pH was lowest at AGRONAM and AQUAVILA where there is a greater freshwater influence of the Mocajuba river. Similarly, Vilhena (2014) found the waters of the Mocajuba estuary to be slightly acidic to neutral with pH values varying from 6.2 to 7.1. The pH in the Marapanim river estuary in Pará ranged between 5.74 and 7.90 (Berrêdo *et al*., 2008) with lowest values in the wet season. Similarly, at Marajó Island, where there is very strong seasonal freshwater inflow, pH values vary from 5.53 to 7.86 (Monteiro *et al*. 2015) and 3.30 to 7.88 (Alves *et al*. 2012). The influence of inflow to the estuary originating from mangrove sediments rich in acidic decomposing organic matter may also contribute to lower pH in the wet season, whereas tidal movements and the greater influence of marine coastal waters may increase estuarine pH in the dry season (Berrêdo *et al.* 2008; Pamplona *et al*., 2013).

Optimal depth for oyster culture is between 0.5 and 3 m (Barnes *et al*. 2007). AGROMAR in Augusto Corrêa is the only oyster culture unit in Pará with a mean depth greater than 4 m in both the wet and dry seasons, and is also the only unit in Pará where on-growing occurs on both long-line and table systems. The shallower waters at the other six units only allow use of the table system.

CONCLUSION

In 2015, data from IBGE (2016) showed that oyster production in four municipalities in Pará was 18.5 tons in Augusto Corrêa (AGROMAR), 8.7 tons in Salinópolis (ASAPAQ), 5.6 tons in Curuçá (AQUAVILA and AGRONAM) and 5.4 tons in São Caetano de Odivelas (ASSOPEF and AMPAP). Among oyster-culture units in Pará state, Brazil, water quality characteristics are either mostly suitable for on-growing of juveniles (higher salinity, higher pH, and greater depth) at ASAPAQ and AGROMAR, or for harvesting of wild spat (lower salinity and lower pH) at AQUAVILA on the Iririteua river and AGRONAM on the Mocajuba river. AQUAVILA dominates comercialization of seed but AGRONAM has begun to harvest spat and comercialize seed on a small scale. Some units have sufficient variation in water quality that allows both activities such as the units in São Caetano de Odivelas (ASSOPEF and AMPAP), but which have low levels of production of adult oysters. Despite water quality characteristics suitable for on-growing, the AAPPNS unit in Maracanã also has a low production due to low level of engagement by association members.

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Figure Legends

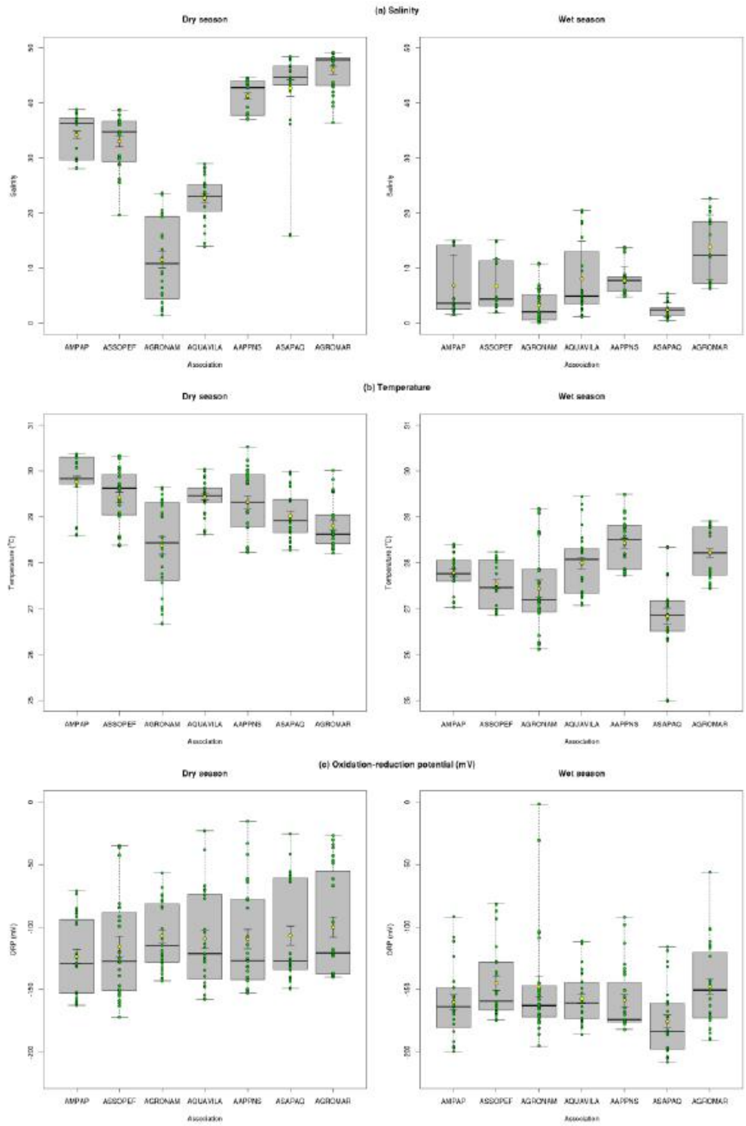

Figure 1 a,b,c. Boxplots of quartiles (minimum, 1st quartile, median, 3rd quartile and maximum), as well as the arithmetic mean (black circle) and standard error (inner error bar) of values of (a) salinity, (b) temperature (ºC), (c) oxidation-reduction potential (mV) (d) pH, (e) depth (m), (f) dissolved oxygen (mg.l^{-1}) and (g) chlorophyll-*a* (mg.m^{-3}) measured at all 7 oyster culture associations along the Pará coast during the 2013 dry season (September to November) and the 2014 wet season (February to April). Chlorophyll-*a* values were measured only in November 2013 and April 2014.

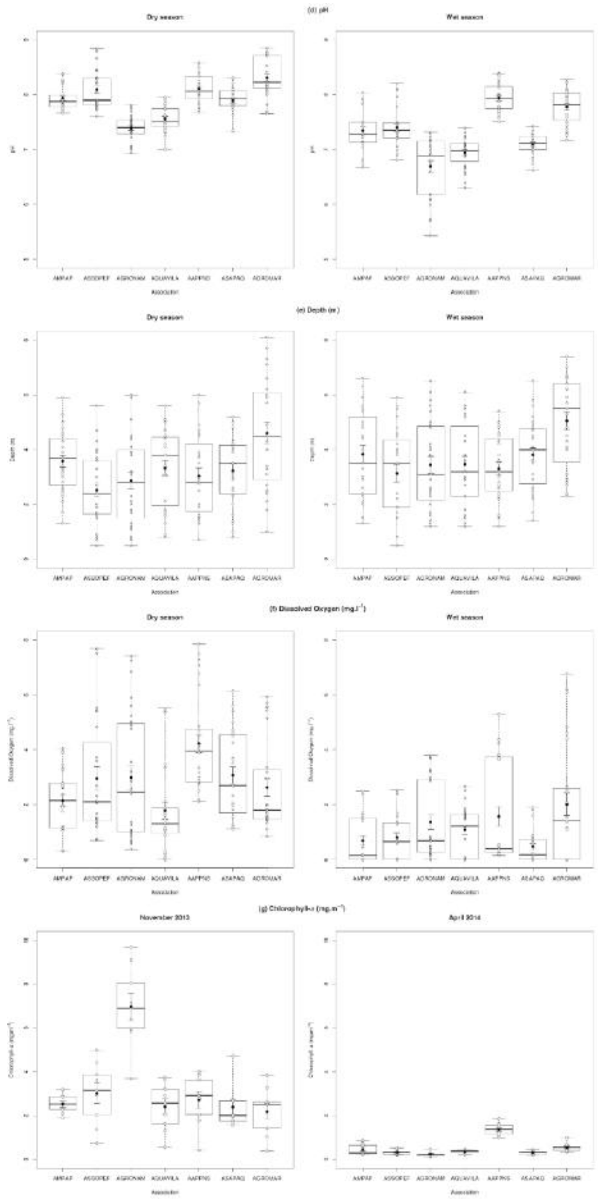

Figure 1 d, e, f, Boxplots of quartiles (minimum, 1st quartile, median, 3rd quartile and maximum), as well as the arithmetic mean (black circle) and standard error (inner error bar) of values of (a) salinity, (b) temperature (ºC), (c) oxidation-reduction potential (mV) (d) pH, (e) depth (m), (f) dissolved oxygen ($mg.l^{-1}$) and (g) chlorophyll-*a* ($mg.m^{-3}$) measured at all 7 oyster culture associations along the Pará coast during the 2013 dry season (September to November) and the 2014 wet season (February to April). Chlorophyll-*a* values were measured only in November 2013 and April 2014.

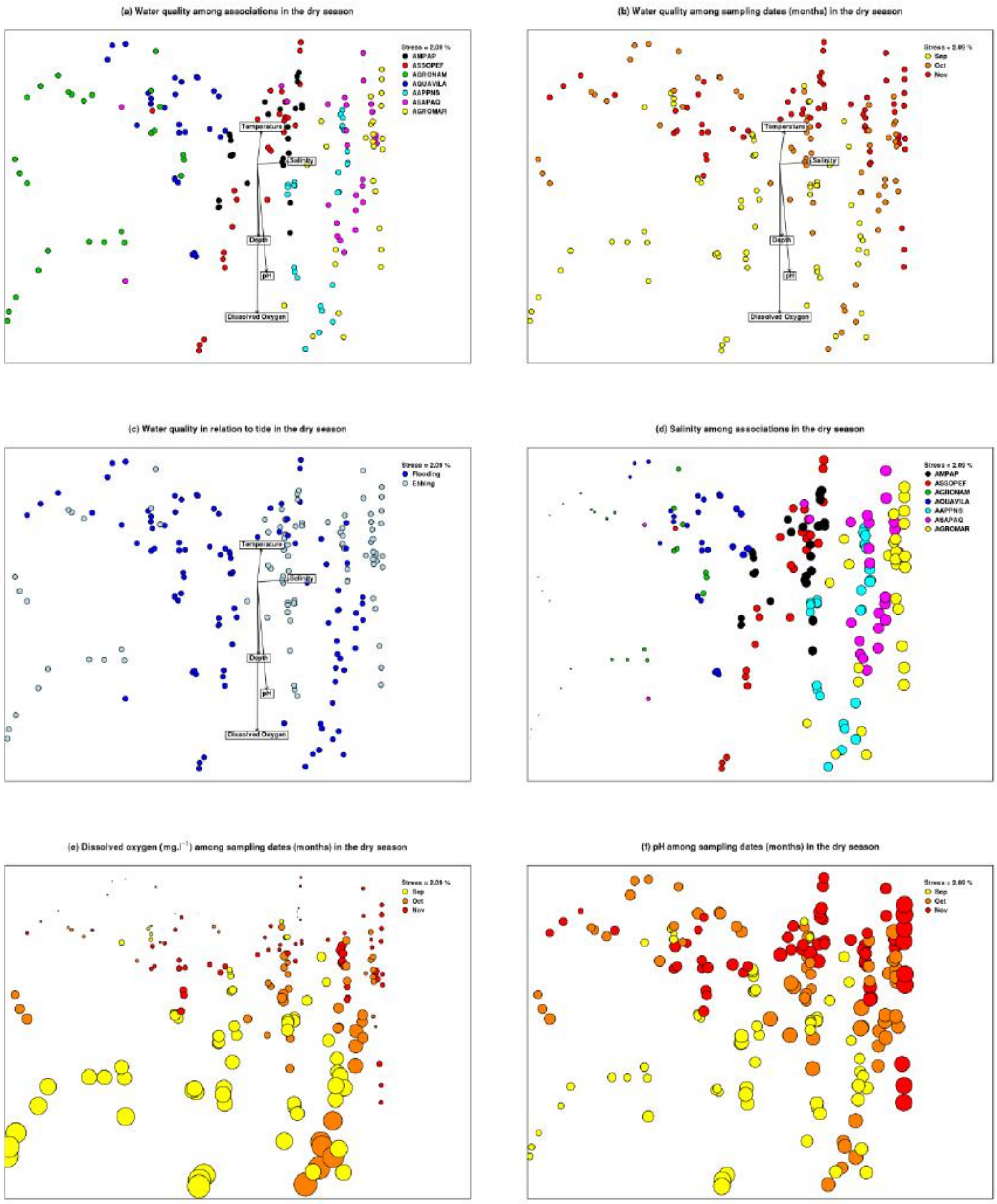

Figure 2a-f. Non-metric multidimensional scaling based on values of salinity, temperature (ºC), oxidation-reduction potential (mV), pH, depth (m), and dissolved oxygen ($mg.l^{-1}$) measured in replicas of water from 7 oyster culture associations along the Pará coast during the 2013 dry season (September, October and November). Superimposed vectors show variables that are significantly correlated with the pattern of replicas. Vector length is proportional to the degree of association. Replicas are color coded according to (a) association, (b) sampling date (month) during the dry season, and (c) tidal state while sampling. Diameter of points in (d), (e) and (f) is proportional to the value of salinity, dissolved oxygen and pH, respectively, measured at each replica.

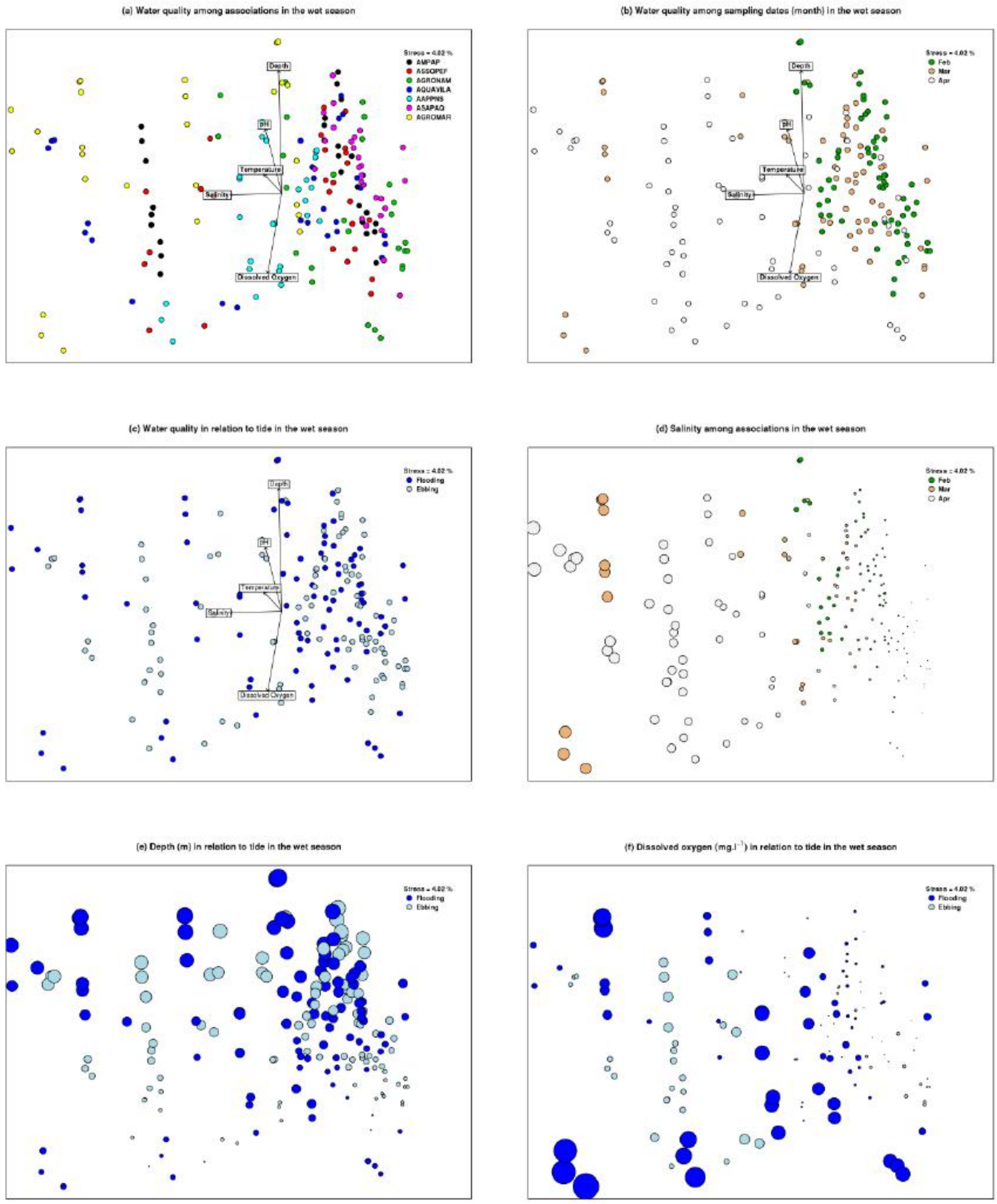

Figure 3a-f. Non-metric multidimensional scaling based on values of salinity, temperature (ºC), oxidation-reduction potential (mV), pH, depth (m), and dissolved oxygen ($mg.l^{-1}$) measured in replicas of water from 7 oyster culture associations along the Pará coast during the 2014 wet season (February, March and April). Superimposed vectors show variables that are significantly correlated with the pattern of replicas. Vector length is proportional to the degree of association. Replicas are color coded according to (a) association, (b) sampling date (month) during the wet season, and (c) tidal state while sampling. Diameter of points in (d), (e) and (f) is proportional to the value of salinity, depth and dissolved oxygen, respectively, measured at each replica.

Table 1. Summaries of analyses of variance (Anova) testing for differences in mean values of salinity, temperature (ºC), oxidation-reduction potential (mV), pH, depth (m), dissolved oxygen ($mg.l^{-1}$) and chlorophyll-*a* ($mg.m^{-3}$) measured at all 7 oyster culture associations along the Pará coast during the 2013 dry season (September to November) and the 2014 wet season (February to April). Chlorophyll-*a* values were measured only in November 2013 and April 2014. Abbreviations: df degrees of freedom, SS Sum of Squares and MS Mean Square. Note differences in df for the smaller number of observations of chlorophyll-*a*.

Source of variation	***df***	***SS***	***MS***	***F***	***P***
Salinity					
Association	6	16541	2757	107.57	< 2.2e-16
Season	1	64196	64196	2504.98	< 2.2e-16
Association × Season	6	10038	1673	65.28	< 2.2e-16
Residuals	364	9328	26		
Temperature (ºC)					
Association	6	50.229	8.371	18.631	< 2.2e-16
Season	1	188.963	188.963	420.544	< 2.2e-16
Association × Season	6	31.368	5.228	11.635	6.254e-12
Residuals	364	163.556	0.449		
Oxidation-reduction potential (mV)					
Association	6	14352	2392	2.0317	0.06073
Season	1	196746	196746	167.1117	<2e-16
Association × Season	6	12625	2104	1.7873	0.10063
Residuals	364	428549	1177		
pH					
Association	6	45.569	7.595	74.7661	< 2.2e-16
Season	1	32.331	32.331	318.2832	< 2.2e-16
Association × Season	6	3.337	0.556	5.4754	1.926e-05
Residuals	364	36.975	0.102		
Depth (m)					
Association	6	133.99	22.3321	9.7275	6.054e-10
Season	1	15.73	15.7260	6.8499	0.009234

Association × Season	6	2.89	0.4814	0.2097	0.973660
Residuals	364	835.66	2.2958		
Dissolved oxygen (mg.l^{-1})					
Association	6	1.4671	0.2445	5.0856	4.974e-05
Season	1	7.0761	7.0761	147.1674	< 2.2e-16
Association × Season	6	1.1894	0.1982	4.1227	0.0005086
Residuals	364	17.5018	0.0481		
Chlorophyll-a (mg.m^{-3})					
Association	6	69.90	11.65	15.70	5.57e-13
Month	1	220.43	220.43	296.95	< 2e-16
Association × Month	6	92.04	15.34	20.66	3.90e-16
Residuals	111	82.40	0.74		

Table 2. Summaries of permutational multivariate (Permanova) analyses of variance testing for multivariate differences among associations, sampling dates (months) and tidal state while sampling, based on values of salinity, temperature (ºC), pH, depth (m) and dissolved oxygen ($mg.l^{-1}$) measured at all 7 oyster culture associations along the Pará coast during the 2013 dry season (September to November) and the 2014 wet season (February to April). Abbreviations: df degrees of freedom, SS Sum of Squares and MS Mean Square.

		Dry season September, October and November 2013					**Wet season February, March and April 2014**				
Source of variation	**df**	**SS**	**MS**	**F**	**R^2**	**P**	**SS**	**MS**	**F**	**R^2**	**P**
Association	6	24537.1	4089.5	179.831	0.79289	0.001	2456.6	409.43	59.135	0.33527	0.001
Month	2	1965.2	982.6	43.208	0.06350	0.001	2112.4	1056.20	152.549	0.28830	0.001
Tide	1	64.6	64.6	2.840	0.00209	0.088	261.2	261.25	37.733	0.03566	0.001
Association × Month	11	559.2	50.8	2.235	0.01807	0.009	1333.7	121.24	17.512	0.18202	0.001
Residuals	168	3820.5	22.7		0.12345		1163.2	6.92		0.15875	
Total	188	30946.5			1.0000		7327.0			1.00000	

Table 3. Associations (r^2), and their significance (P), between physical-chemical variables and the ordination by multidimensional scaling (Envfit) of replicas, based on values of salinity, temperature (ºC), pH, depth (m) and dissolved oxygen ($mg.l^{-1}$) measured at all 7 oyster culture associations along the Pará coast during the 2013 dry season (September to November) and the 2014 wet season (February to April).

Season	**Dry** September to November 2013		**Wet** February to April 2014	
Variable	r^2	P	r^2	P
Salinity	0.9999	0.0001	0.9984	0.0001
Temperature (ºC)	0.0604	0.0026	0.1395	0.0002
pH	0.5337	0.0001	0.3465	0.0001
Depth (m)	0.2031	0.0001	0.8914	0.0001
Dissolved oxygen ($mg.l^{-1}$)	0.8512	0.0001	0.4564	0.0001

CAPÍTULO

3

Settlement, growth and commercialization of native oysters *Crassostrea gasar* cultivated in Amazonian mangrove estuaries*.

DIONISO DE SOUZA SAMPAIO

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ARTHUR dos S. SILVA

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CRISTIANA RAMALHO MACIEL

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* Submetido ao periódico científico

PESQ. AGROP. BRASILEIRA (QUALIS B2) – BIODIVERSIDADE

(ANEXO 03)

Settlement, growth and commercialization of native oysters *Crassostrea gasar* cultivated in Amazonian mangrove estuaries

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Abstract - Settlement, seed size, larval development in the laboratory, growth and aspects of the commercialization of native oysters *Crassostrea gasar* cultivated in Pará were investigated between 2012 and 2016 at 5 culture units over periods varying between 6 to 12 months. Seed size differed between December 2014 (21 mm) and April 2015 (12 mm) and smaller size may be related to greater rainfall. Numbers of native seed were higher in the on-growing area and exotic seed abundance was low. Larval development is best at salinities of 16 and 21 in which the pediveliger stage was reached after 53 days. On-growing was variable but market size was reached in at least 4 months at Agromar, Aappns and Asapaq. Mortality varied from 19% to 46%, comparable to other Brazilian *C. gasar* cultures. Mass of oysters varied monthly and between culture units, related to size selection before sale. On average, oysters in the classes Baby and Médio are 77% and 80% shell by mass. Most oysters sold at Agromar are within the class size limits, whereas those sold at Aquavila are much larger. The Aquavila unit is suitable for seed harvesting, whereas the Agromar unit, has the lowest mortality and is suitable for on-growing.

Index terms: cupped oyster; aquaculture; shell, length; mass; mortality.

Assentamento, crescimento e comercialização de ostras nativas *Crassostrea gasar* cultivadas em estuários de manguezais amazônicos

Resumo - Assentamento, tamanho da semente, desenvolvimento larval no laboratório, crescimento e aspectos da comercialização de ostras nativas *Crassostrea gasar* cultivadas no Pará foram investigados entre 2012 e 2016 em 5 cultivos em períodos de 6 a 12 meses. Comprimento das sementes diferiu entre dezembro de 2014 (21 mm) e abril de 2015 (12 mm) e menor tamanho parece associado a maior precipitação. Números de sementes nativas foram maiores na área de engorda enquanto abundância de sementes exóticas foi baixa. O desenvolvimento larval é melhor em salinidades de 16 e 21, nas quais o pedivéliger apareceu após 53 dias. O crescimento foi variável, mas o tamanho de mercado foi atingido em pelo menos 4 meses em Agromar, Aappns e Asapaq. A mortalidade variou de 19% a 46%, comparável a outros cultivos de *C. gasar*. Massa de ostras varia mensalmente e entre cultivos, relacionadas à seleção de tamanho pré-venda. Em média, ostras nas classes Baby and Médio são 77% e 80% concha. A maioria das ostras vendidas na Agromar é dentro dos limites da classe, enquanto as vendidas na Aquavila são maiores. Aquavila é adequada para a colheita de sementes, enquanto que Agromar tem a menor mortalidade e é adequada para a engorda.

Termos para indexação: ostra, aquicultura, concha, comprimento, peso, mortalidade.

Introduction

Crassostrea rhizophorae (Guilding, 1828) and *Crassostrea gasar* (Adanson, 1757), also known as *Crassostrea brasiliana* (Lamarck, 1819), are native oyster species that are commercially harvested or cultivated in Brazil (Varela et al., 2007; Melo et al., 2010a; Lazoski et al., 2011). Both species have been shown to be commercially viable in both southeastern (Lopes et al., 2013) and northern (Alcântara-Neto, 2003; Hoshino, 2009; Macedo et al., 2016) Brazil. Despite this technical and economic viability, native oysters account for a low proportion of oyster production in Brazil (Campbell & Pauly, 2013; Pauly & Zeller, 2015). In contrast, *Crassostrea gigas* (Thunberg, 1793), an exotic species from the Pacific cultivated in southern Brazil since the 1970s (Melo et al. 2010a; Suplicy et al. 2015) has the highest production in Brazil (Ostrensky et al., 2008; Carranza et al. 2009).

Crassostrea gasar is a potentially important species for commercial, community and family-based oyster production in Brazil (Macedo et al., 2016; Brabo et al., 2016). Settlement and growth in native Brazilian oysters has been investigated in São Paulo (Pereira et. al., 2001; Pereira et. al., 2003), Santa Catarina (Silveira et al., 2011; Lopes et al., 2014), Maranhão (Funo et al., 2015), Paraná (Montanhini-Neto et al., 2013) and Espírito Santo (Alvarenga & Nalesso, 2006). Along the coast of the state of Pará, in northern Brazil, the native mangrove oyster, *Crassostrea gasar* has been cultivated since 2006 in the municipalities of Augusto Corrêa, Salinópolis, Maracanã, Curuçá and São Caetano de Odivelas (Sampaio and Boulhosa 2007; Hoshino, 2009). Seed, harvested from the wild at the AQUAVILA unit in Curuça, is sold to all the other units for on-growing (IBGE, 2015). Another nearby unit, AGRONAM located in Nazaré de Mocajuba, Curuçá, has recently begun to harvest seed for sale (*pers. obs*.).

Despite the growing importance of mangrove oyster cultivation for local communities along the Pará coast, little is known about settlement, growth rates and the sizes of oysters sold commercially in the region, with a single study on oyster reproduction (Paixão et al., 2013). The objective of the present study is to quantify settlement, growth and size of commercial oysters grown in culture at 5 of the 7 oyster culture associations in operation along the Pará coast (Figure 1), as well as explore the potential to raise native oyster seed in the laboratory.

Materials and Methods

Settlement of native and exotic seed

Between October 2014 and June 2015, experimental seed harvesting was carried out in two areas, one used for on-growing and the other for seed harvesting, in the Aquavila oyster culture unit situated on the Iririteua river, municipality of Curuça (Figure 2). The seed harvesting collectors were the same as those used by oyster growers, composed of 20 plastic plates, cut from soft drinks bottles, separated vertically 5 cm from the next, and hung vertically such that the uppermost plate was 80 cm from the river bed and the lowermost plate was 50 cm from the river bed. A total of 10 seed harvesting collectors were used each month (a total of 200 plates). Each collector plate was 0.25 m^2 in area. The seed collectors were left for an average of 59 days after which they were removed and all seed of both native and exotic *Crassostrea* species were counted. A sample of 50 oyster seed were selected randomly for measurement of their maximum dimension from the umbo to the ventral margin, henceforth “length” (mm), using a digital calipers with a precision of 0.01 mm. Differences in length between both areas and among sampling dates were verified using two-factor analysis of variance (ANOVA).

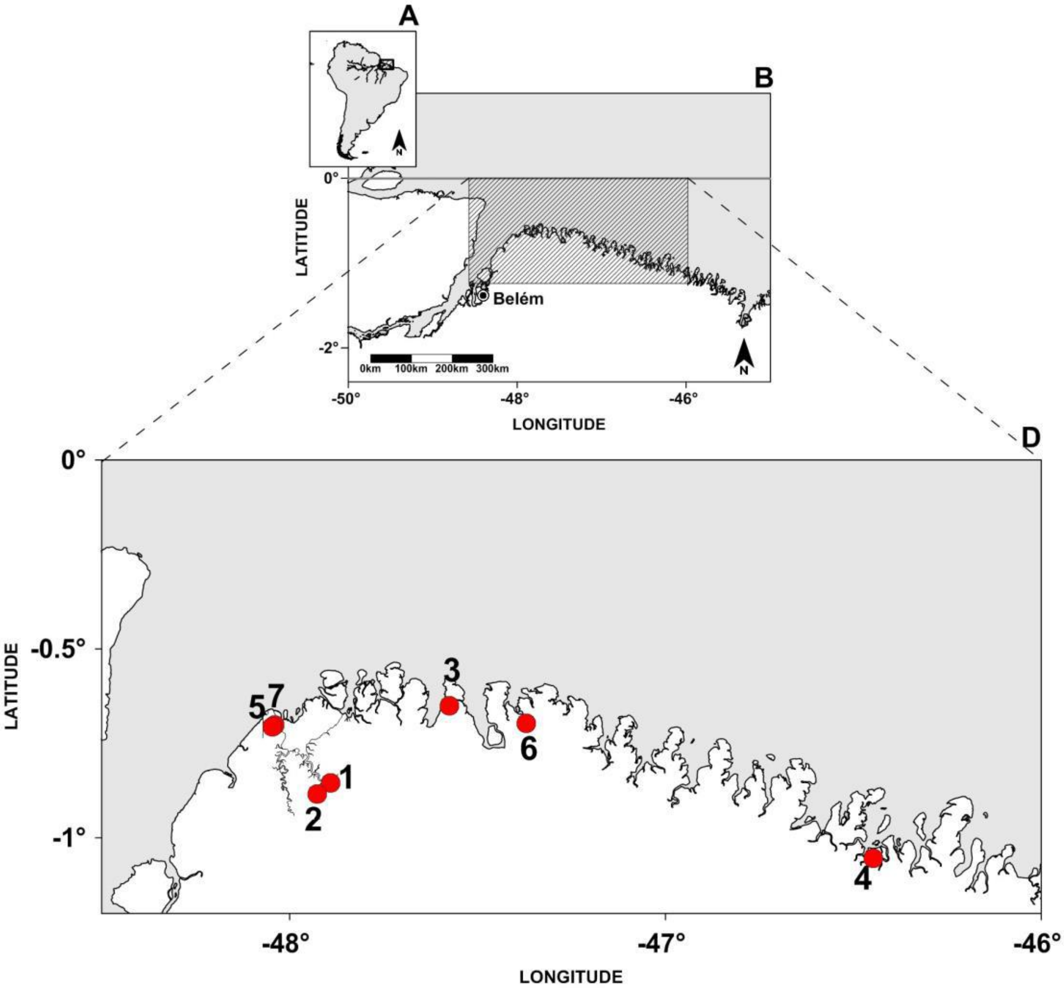

Figure 1 Location on the northern coast of South America (A), of the study area, along the northeastern coast of Pará state of oyster culture associations, municipality. 1:Aquavila, Curuçá; 2:Agronam, Curuçá; 3:Aappns, Maracanã; 4:Agromar, Augusto Corrêa; 5:Ampap, São Caetano de Odivelas; 6:Asapaq, Salinópolis and 7:Assopef, São Caetano de Odivelas.

Figure 2 Seed collectors installed in the on-growing area (Left) and in the seed harvesting area (Right).

Fertilization and larval development in the laboratory

Oysters (length >100 mm) sampled from Agromar and Aquavila in June to October 2014 and February to November 2015 were used to obtain gametes. On arrival in the laboratory, these were immediately cleaned and washed and maintained in filtered purified saltwater. Attempts to induce spawning included keeping the oysters out of the water at a temperature of 18°C for two hours and subsequently transferring them to a 300 L tank of salt water at a temperature of 27.5°C (±1°C). If the latter was not successful, the oysters were subjected to osmotic shock in salinity 15 followed by an increase to salinity 30. The use of oxygen peroxide as well as placing oyster spermatozoa, obtained from gonad smears, in the water. In vitro insemination was carried out placing selected mature spermatozoa and eggs (Castilho-Westphal et al., 2015) in a 60 ml beaker. After a few minutes, the water and gametes were transferred to a 2 L vessel. Larval development was tested at salinities of 16, 21, 26 e 31, with 3 replicas each. Water was changed on alternate days using 32 µm, 53 µm, 125 µm e 212 µm sieves to retain the larvae and any organic matter. Larvae were fed with the algae *Nannochloropsis oculata* and species of *Isochrysis* and *Chaetoceros*. After each exchange of water, larval stages were monitored using an inverted microscope.

Growth and mortality

An initial cohort of 500 seed (<30 mm in length, or 2 months old on average) was followed at each of 5 oyster culture units (Agromar, Aquavila, Aappns, Asapaq and Assopef) that use the mesh bag culture method for on-growing. Once a month, a sample of 50 individuals was measured for length (mm) using a digital calipers with a precision of 0.01 mm and the number of dead individuals was counted. Cohorts were followed for between 6 to 12 months. Oysters were transferred to larger on-growing mesh bags as growth progressed. Length (mm) at age (months) data for each culture unit were fitted to the von Bertalanffy growth model($L_t = L_{inf} \times [1 - e^{-K\times(t-t_0)}]$), where L_t is the length at time t, L_{inf} is the asymptotic length, *e* is the mathematical constant 2.718..., *K* is the population rate of increase in length over time and t_0 is the initial time, using the non-linear least squares function *nls()* in GNU-R (R Core Team, 2017) and the *nlstools* contributed package (Baty et al., 2015). The number of survivors in each of three cultures was calculated each month subtracting the number of dead individuals from the total of the previous month. Percentage cumulative survival and mortality, as well as mortality as a percentage of the total number of dead oysters, were calculated monthly.

Market ready oysters

Once a month, between February 2015 and January 2016, a sample of 50 market-ready oysters in the classes Baby (60-79 mm) and Médio (80-99 mm) was obtained from the culture units at Aquavila in Curuça and Agromar in Nova Olinda, and oyster in each class were measured for length (mm) using a digital calipers with a precision of 0.01 mm. Additionally, the mass (kg) of each of n=4 dozen oysters in each class (Baby and Médio) was measured with a precision of 0.001 kg. Differences in length and mass among months and between culture units were analyzed using two-factor ANOVA. All data were analyzed using GNU R version 3.3.3 (R Core Team, 2017).

Results and Discussion

Settlement of native and exotic seed

Seed harvested from the Iririteua river at the Aquavila culture unit did not differ in mean length between on-growing and seed harvesting areas (Table 1, Table 2). However, there were differences among sampling dates where, in both areas, mean length was significantly greater in December 2014 (21 mm) and lower in April 2015 (12 mm) (Table 1, Table 2). Variation in length was lower in December 2014 and was similar but greater on the other sampling dates

(Table 2). Mean length of seed at Aquavila in Lauro Sodré, Curuça appears associated with monthly accumulated rainfall (mm) which, at the nearest meteorological station (A202) in Castanhal, was 11.6 mm in December 2014 and 232.0 mm in April 2015 (INMET, 2016). Mean length of oyster *Crassostrea rhizophorae* seed, harvested from Pacatuba, Sergipe state and brought to the Piraquê-Açú river in Espírito Santo state for on-growing, was 6.16 ± 0.97 mm (Alvarenga & Nalesso 2009), well below the lowest value of 12.00 ± 210 mm recorded from Aquavila in April 2015 (Table 2).

Settlement of native *Crassostrea gasar* was consistently greater in the on-growing area, especially in February 2015 (Figure 3a). In the seed harvesting area, the number of seed decreased consistently over time between October 2014 and June 2015, when, no settlement occurred on the latter sampling date (Figure 3a). Settlement of exotic *Crassostrea* was sporadic and in very low numbers over the same period (Figure 3b). In Brazil, *C. brasiliana* and *C. rhizophorae* seed with a length of at least 20 mm is capable of spawning (Nascimento, 1978; Galvão et al. 2000). Therefore, on-growing areas may contribute to increased settlement due to higher numbers of larvae produced by the oysters in culture or by attracting larvae due to the presence of con-specifics (Silveira et al., 2011).

Pará is the only Brazilian state that has an officially registered unit (Aquavila, Lauro Sodré, Curuça) harvesting *Crassostrea gasar* seed from the wild; those in Rio de Janeiro and Santa Catarina are laboratory based seed production units (IBGE, 2015). Seed harvesting has increased annually in Pará state, with the municipality of Curuçá leading the production by harvesting 900 thousand seed in 2013, 1,000 thousand in 2014 and 2,480 thousand in 2015. The revenue from harvesting seed between 2013 and 2015 was estimated at R$387,000 (US$118,200 June 2017) for Curuça (IBGE, 2015). In the same period, the municipality of São João de Pirabas, which is not officially a producer of oysters, was registered as harvesting

70 thousand seed in 2015 generating a revenue of R$3.000,00 (US$916 June 2017) (IBGE, 2015).

Harvesting of wild seed is risky as over-harvesting of natural oyster beds, pollution and disease may interrupt the supply of seed. There may be potential for the production of larvae in the laboratory as successful fertilization of oyster gametes was achieved under laboratory conditions using gonad smears and induced spawning events. A total of 19 attempts were carried out, and although results were variable, both methods are generally successful with the use of four stimuli together, namely, an initial reduction in temperature, followed by thermal shock, osmotic shock, hydrogen peroxide and addition of spermatozoa from gonad smears. The use of osmotic shock probably contributed to spawning, since variation in salinity appears important for reproductive development and spawning at the Agromar culture unit (Paixão et al., 2013). At salinities of 16 and 21, trochophore larvae were observed after 6 to 12 hours, D larvae after 24 hours, umboned veliger larvae after the 19th day, the veliger larva after the 25th day and the pediveliger larva after the 53rd day. Although it was not possible to obtain seed, it is evident that moderate salinity is important for larval survival of *Crassostrea gasar* along the Pará coast. Salinities of 26 and 31 resulted in total mortality of larvae on the second day, whereas salinities of 16 to 21 were best for larval development. However, a lot of work remains to be carried out in order to complete the life-cycle in the laboratory and produce seed, as well as scale up production for commercial supply (Galvão et al., 2000; Christo et al., 2010; Antônio, 2013).

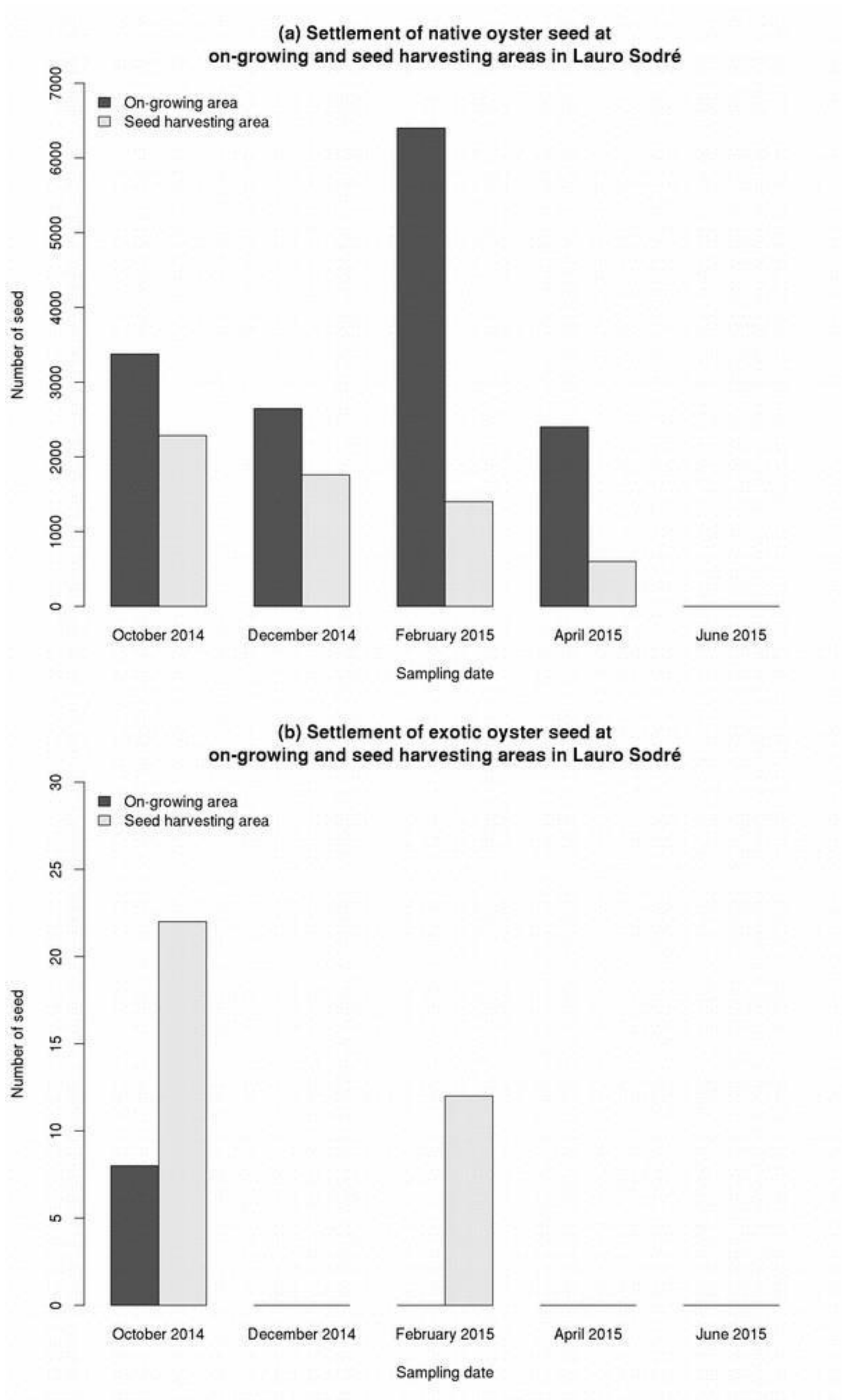

Figure 3 Settlement of native (a) and exotic (b) seed of *Crassostrea* in on-growing and seed harvesting areas at the AQUAVILA association, Lauro Sodré, Curuça between October 2014 and June 2015.

Growth and Mortality

Growth of oysters varied markedly among the five (5) culture units. The oyster culture associations AGROMAR in the municipality of Augusto Corrêa, AAPNS in Maracanã, AQUAVILA in Curuçá between November 2013 and July 2014, and ASAPAQ in Salinópolis, growth followed the von Bertalanffy curve with K varying between 0.097 and 0.97 and L_∞ varying from 48.3 to 103 mm (Figure 4a,d,e). At AQUAVILA between September 2012 and August 2013 and at ASSOPEF in the municipality of São Caetano de Odivelas, growth was linear and did not reach an asymptote, despite individuals being monitored up to 14 months of age (Figure 4b,c).

The variation among culture units is very notable even at the same unit at different times, for example AQUAVILA (Figure 4b,e). Units with the largest asymptotic lengths are AGROMAR, AAPPNS and ASAPAQ where oysters can reach 60 mm (class Baby) in 4 to 5 months, and over 80 mm (Médio) in 10 to 11 months (Figure 4a,d,f). By comparison, at AQUAVILA and ASSOPEF, the time to reach class Baby is 8 to 9 months, and to reach class Médio, 10 to 11 months (Figure 4b,c), which is not always possible, as was the case at AQUAVILA between November 2013 and July 2014 (Figure 4e). *Crassostrea rhizophorae* reached a length of only 37.6 mm in 10 months of on-growing in the Piraquê-Açú river in Espirito Santo state (Alvarenga & Nalesso 2009).

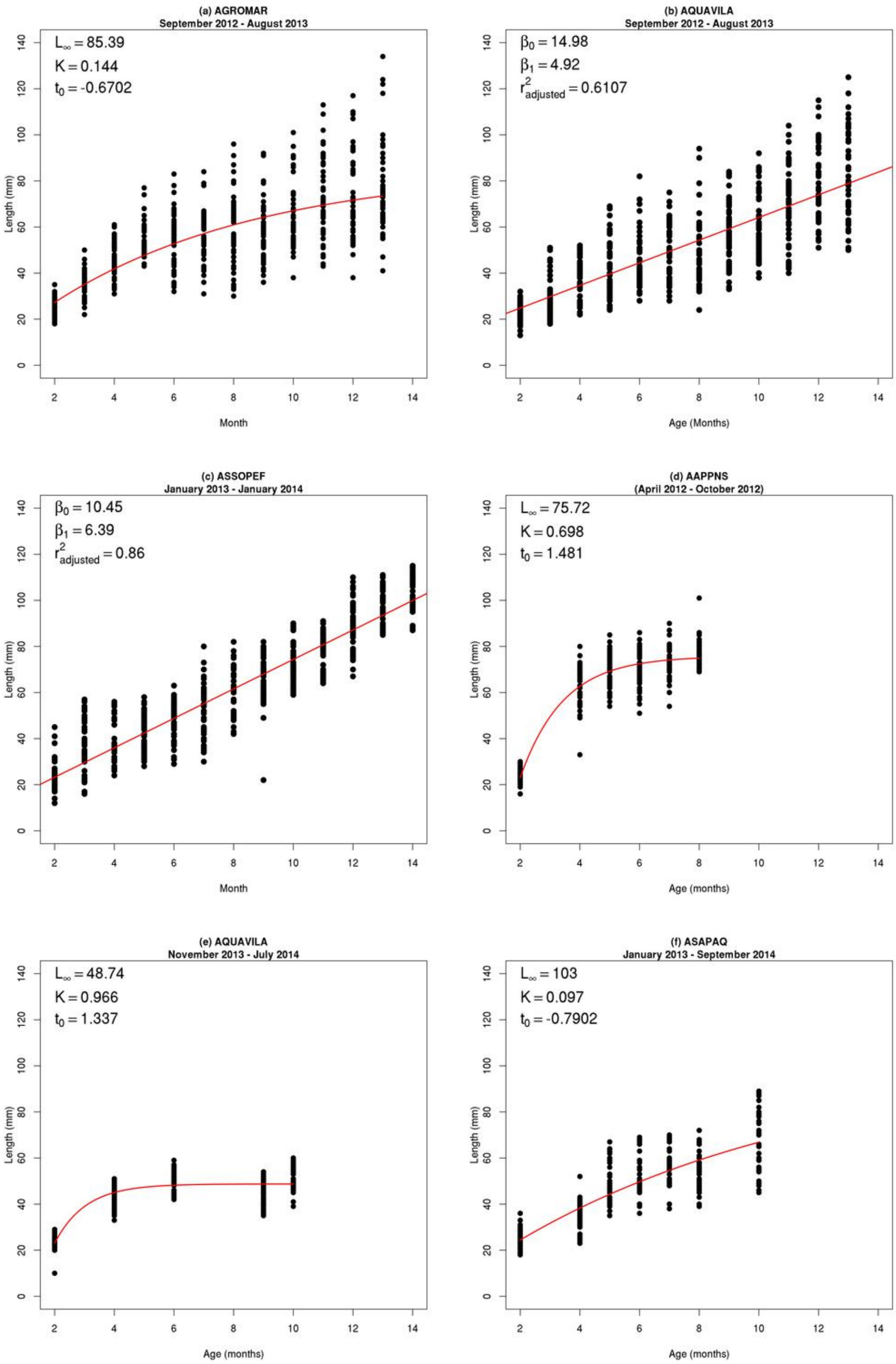

Figure 4 Age at length data of *Crassostrea gasar*, fitted to the von Bertalanffy growth equation, from five culture units (a) AGROMAR, (b,e) AQUAVILA, (c) ASSOPEF, (d) AAPPNS and (f) ASAPAQ in Pará state, Brazil. See Figure 1 for the locations of the culture units.

Total accumulated mortality at the end of each period was lowest for AGROMAR (19.2%) and greatest for both AQUAVILA and ASSOPEF at 46% each. At AGROMAR, mortality was greatest in November 2012, and in January, March and April 2013 and 86% of the total number of deaths occurred between October 2012 and April 2013. At AQUAVILA, mortality was greatest, 87%, in a much shorter period between October and December 2012. At ASSOPEF, a mortality was greatest, 92%, between February and July 2013. By comparison, mortality ranged from 10 to almost 50% at *Crassostrea gasar* cultures at Cananéia, São Paulo (Pereira et al., 2001), which are comparable to the values observed in the present study.

Market-ready oysters

Mean length (mm) of oysters in the classes Baby and Médio sold by AQUAVILA, Lauro Sodré, varied significantly among months ($F_{11,564}$=14.2, p<0.001 and $F_{11,564}$=7.9, p<0.001, respectively) as well as at AGROMAR, Nova Olinda ($F_{11,564}$=4.0, p<0.001 and $F_{11,564}$=16.9, p<0.001, respectively). Mean length of class Baby oysters at AQUAVILA was lower in July, August and December 2015 and greater between April and June and between September and November 2015 and in January 2016, and similar in the other months (Table 3, Figure 5). Class Baby oysters from AGROMAR were larger in May, August and September 2015, and in December 2016, and similar in the other months (Table 3, Figure 5). Oysters in class Média at AQUAVILA were larger in April and July 2015, and in January 2016, and smaller in February, May and December 2015. Class Média oysters from AGROMAR were larger in June 2015 and between August 2015 and January 2016, and smaller between February and May 2015 (Figure 5). The average size of oysters was significantly greater in AQUAVILA (Baby: 83.27 ± 7.32 mm, Médio: 100.58 ± 8.42 mm) in comparison with AGROMAR (74.33 ± 4.94 mm, Médio: 89.80 ± 6.78 mm) ($F_{1,1102}$=555.2, p<0.001 e

$F_{1,1102}=573.8$, $p<0.001$, respectively). Additionally, mean length in class Baby was more similar to Média in oysters from AQUAVILA than in oysters from AGROMAR (Figure 5a).

There was greater variability in length of oysters at AQUAVILA in comparison with those at AGROMAR (Figure 5ab). The proportion of individuals in the length frequency distribution in relation to the size limit of the classes Juvenile (<60 mm), Baby (60-80 mm), Média (80-100 mm) and Master (>100 mm), show that oysters from AQUAVILA are larger than the size limits of both Baby and Média sales classes. Only 32% of oysters sold as class Baby by AQUAVILA are actually within the class size limits and a striking 67% are larger. In contrast, of the class Baby oysters sold by AGROMAR, 85% are within the class limits and only 14% are larger. Of the oysters sold as class Média by AQUAVILA, 40% are within the class limits and 58% are larger. Again, in contrast, of the class Média oysters sold by AGROMAR, 88% are within the size limits and only 7.5% are larger.

Mean mass of a dozen oysters (kg) in both classes Baby and Média varied significantly among months, and between the two culture units AQUAVILA and AGROMAR (Figure 6, Table 3). The average mass of a dozen oysters was significantly greater in AQUAVILA (Baby: 0.95 ± 0.14 kg, Médio: 1.43 ± 0.15 kg) in comparison with AGROMAR (0.89 ± 0.15 kg, Médio: 1.33 ± 0.20 kg). However, there was significant interaction between sampling date and culture unit in terms of mean mass of a dozen oysters in both classes. Larger differences in mass of class Baby oysters among the culture units occurred in February, March (AGROMAR>AQUAVILA), in April and May (AQUAVILA>AGROMAR), in July and August (AGROMAR>AQUAVILA) and in November 2015 to January 2016 (AQUAVILA>AGROMAR). In June, September, October and December 2015 mean mass of class Baby oysters is similar in each culture unit. Larger differences in mass of class Médio oysters among the culture units occurred in April and July (AQUAVILA>AGROMAR), in August (AGROMAR>AQUAVILA) and in November and December 2015

(AQUAVILA>AGROMAR). In February, March, May, June, September, October 2015, and in January 2016 mean mass of class Médio oysters is similar in each culture unit.

The mean mass of the commercial classes Baby and Médio for oysters sold at Agromar and Aquavila, between September 2012 and August 2013 were 0.9 kg and 1.4 kg, respectively, and which are greater than the value suggested by EPAGRI, Santa Catarina state, for fisheries statistics (Alex Santos – Personal Communication), which is that 1 dozen oysters equals 1 kilogram.

The % of the oyster as shell in class Baby oysters sold from AQUAVILA varied between 68.7% and 86.4% with a mean of 79 ± 0.05% and in oysters from AGROMAR varied between 58.4% and 84.4% with a mean of 76 ± 0.06%. The % of the oyster as shell in class Média oysters sold from AQUAVILA varied between 74.9% and 87.5% with a mean of 82 ± 0.06% and in oysters from AGROMAR varied between 74.0% and 88.7 with a mean of 79 ± 0.03%. Since the shell is considered a solid residue in the oyster culture supply chain, for future analyzes estimates of 77% shell for oysters in the class Baby and 80% shell for oysters in the class Médio may be recommended.

Conclusions

The association at Aquavila in Curuçá is suitable for seed harvesting from the wild. The abundance of an exotic *Crassostrea* species is low and appears not to hinder native seed harvests, which are increasing annually. Lowest mortality occurs at AGROMAR and this is one of the three units with the faster growth, where market size may be reached in at lesat 4 months. AQUAVILA sells most of its oysters above the upper limit of each of the classes Baby and Médio, whereas AGROMAR sells most of their oysters within the correct size ranges.

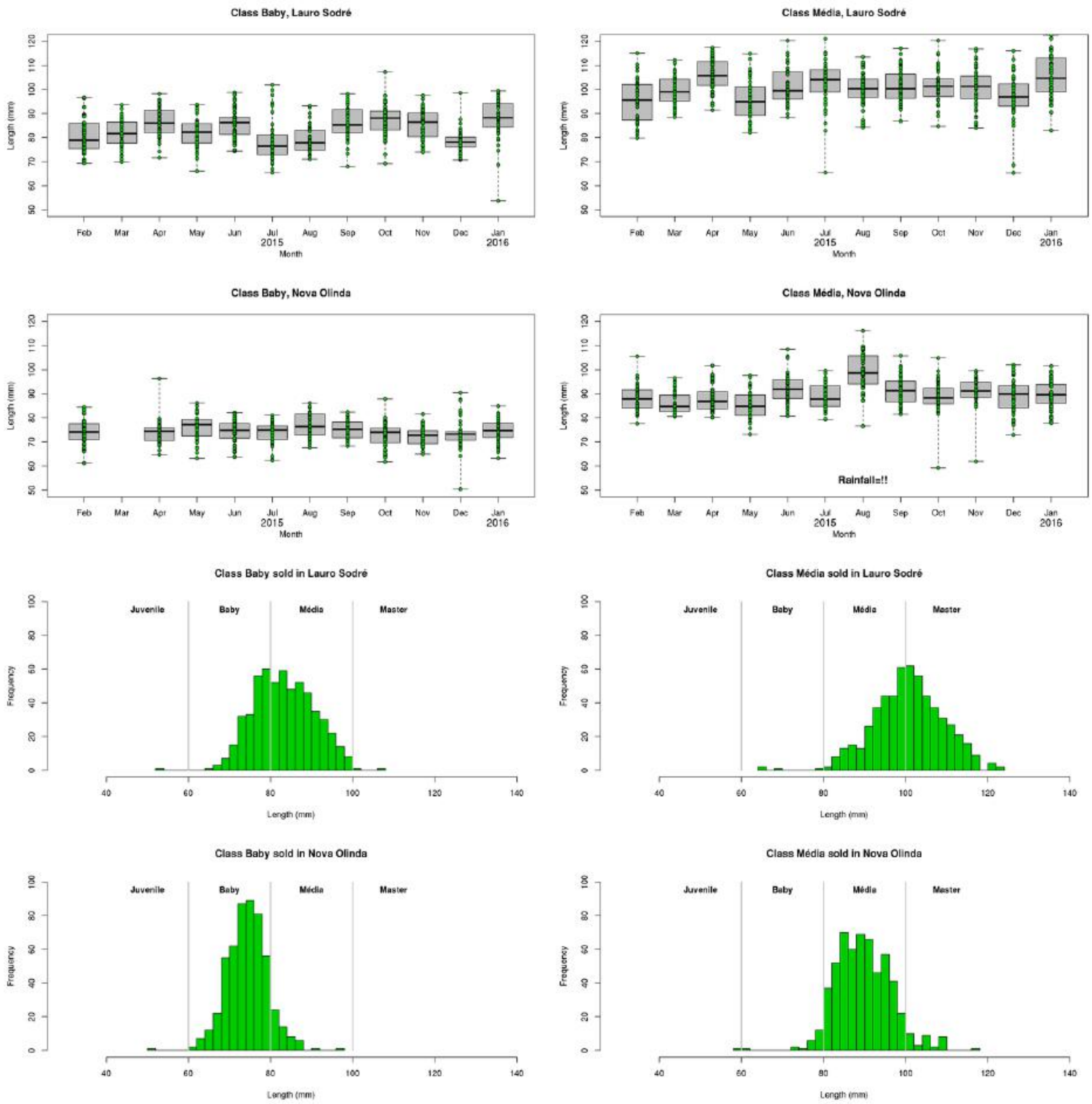

Figure 5 Boxplots of length (mm) and length frequency distributions of native oysters *Crassostrea gasar* in the classes Baby and Média, sold between February 2015 and January 2016, at the AQUAVILA association, Lauro Sodré, Curuça and the AGROMAR association, Nova Olinda, Augusto Corrêa.

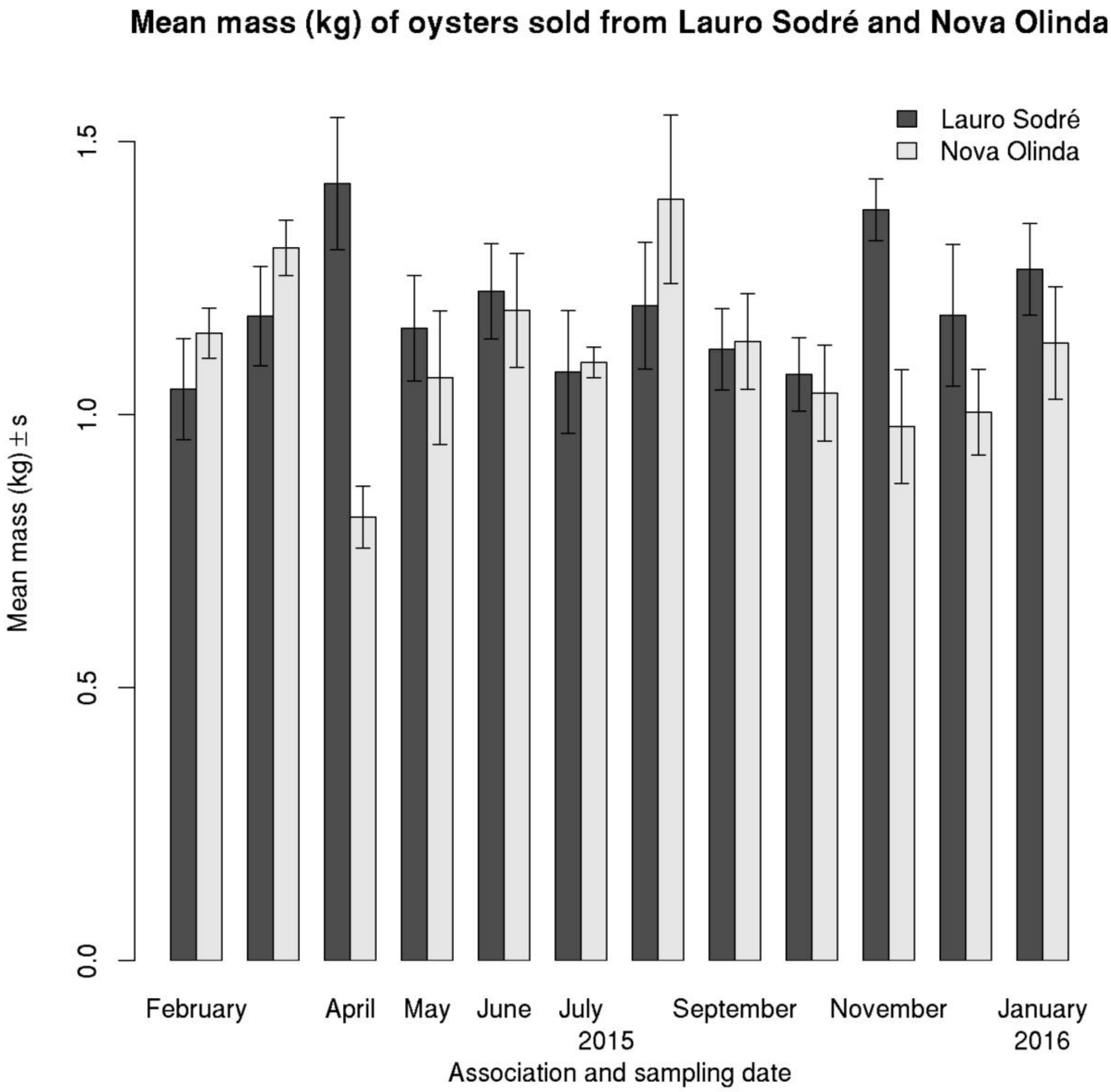

Figure 6 Boxplots of mean mass (kg) distributions of native oysters *Crassostrea gasar*, between February 2015 and January 2016, at the AQUAVILA association, Lauro Sodré, Curuça and the AGROMAR association, Nova Olinda, Augusto Corrêa.

Acknowledgements

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Table 1 ANOVA summary of the differences in mean length (mm) of native oysters *Crassostrea gasar* in on-growing and seed harvesting areas between October 2014 and April 2015 at the AQUAVILA association, Lauro Sodré, Curuça.

Source of variation	**df**	**Sum of Squares**	**Mean Square**	**F**	**P**
Area	1	0.0	0.2	0.009	0.9250^{ns}
Sampling Date	3	4452	1484	64.908	$<2e\text{-}16^{***}$
Interaction Area and Sampling Date	3	166	55.2	2.414	0.0663^{ns}
Residuals	392	8963	22.9		

Table 2 Mean length ± standard deviation (mm) of native oysters *Crassostrea gasar* in on-growing and seed harvesting areas between October 2014 and April 2015 at the AQUAVILA association, Lauro Sodré, Curuça.

Area	**Sampling Date**	**Mean length ± sd (mm)**
On-growing area	October 2014	17.9 ± 3.6
Seed harvesting area	October 2014	19.9 ± 6.5
On-growing area	December 2014	21.5 ± 5.7
Seed harvesting area	December 2014	20.9 ± 5.9
On-growing area	February 2015	18.8 ± 5.4
Seed harvesting area	February 2015	17.4 ± 4.8
On-growing area	April 2015	12.0 ± 2.1
Seed harvesting area	April 2015	12.3 ± 2.1

Table 3 ANOVA summaries of the differences in mean mass (kg) of a dozen native oysters *Crassostrea gasar* in the classes Baby and Média, sold between February 2015 and January 2016 at the AQUAVILA association, Lauro Sodré, Curuça and the AGROMAR association, Nova Olinda, Augusto Corrêa.

		Baby				**Média**			
Source of variation	**df**	**Sum of Squares**	**Mean Square**	**F**	**P**	**Sum of Squares**	**Mean Square**	**F**	**P**
Month	11	0.4008	0.03643	10.83	1.89e-11***	1.0140	0.09219	17.55	2.84e-16***
Association	1	0.1071	0.10707	31.82	3.12e-07***	0.2606	0.26063	49.61	9.19e-10***
Interaction Month and Association	11	1.3935	0.12668	37.64	<2e-16***	1.5556	0.14142	26.92	< 2e-16***
Residuals	72	0.2423	0.00337			0.3782	0.00525		

CONCLUSÃO GERAL

As principais conclusões dos estudos descritos nos artigos que compõem essa Tese de Doutorado estão apresentadas abaixo:

<u>Capítulo 1</u>

Oyster culture on the Amazon mangrove coast: asymmetries and advances in an emerging sector.
Cultivo de ostras na costa de manguezal da Amazônia: assimetrias e avanços em um setor emergente.

- Desde o início das atividades em 2006, a cultura ostra no estado do Pará tem sido assistida 100% por projetos financiados pelos governos e por projetos de pesquisa, mas desde 2010 existem associações com capacidade de compra de insumos e equipamentos.

- O setor cresceu em termos de estrutura; capacidade de produção; número de pessoas envolvidas na atividade; número de associações devido a projetos aprovados pelo Governo Federal para a compra de equipamentos e insumos.

- Conflitos entre ostreicultores e extrativistas foram observados no período do estudo. Destacamos o município de Curuçá, com conflitos de extrativistas e produtores de ostras. Em um determinado período os ostreicultores tratavam os extrativistas como os vilões da cadeia produtiva.

- A cadeia produtiva do Estado do Pará depende exclusivamente das sementes de ostras comercializadas da comunidade de Lauro Sodré no município de Curuçá. Nos últimos cinco anos outros grupos vêm se dedicando à captação de sementes como, por exemplo, a Associação de Nazaré do Mocajuba e de grupos no município de São João de Pirabas. Nas estatísticas oficiais o Pará é o único estado que faz captação de sementes de ostras em ambiente natural.

- A necessidade de transição para um modelo do Cooperativismo é de fundamental importância para a organização produtiva e para o crescimento com sustentabilidade. Uma cooperativa pode por lei comercializar, e existem grupos com maturidade para essa transição.

- O Estado do Pará necessita urgente de uma legislação como o estado de São Paulo que foi criada na década de 80, e que determinou o defeso e o tamanho de captura de ostras, ou seja, protege os bancos naturais de moluscos do Litoral de São Paulo até o Paraná. Existem bancos naturais no município de Curuçá que estão altamente impactados pelo extrativismo desordenado.

- O Plano Local de Desenvolvimento da Maricultura (PLDM) foi apresentando e o projeto foi realizado com delimitação em áreas específicas nos seguintes municípios de Curuçá; Salinópolis; São João da Ponta e São João de Pirabas com uma área total de 172 ha. Até o momento o PLDM do Pará não foi implementado. Segundo os ostreicultores dos municípios de Curuçá e Salinópolis a equipe executora do PLDM não procurou as pessoas envolvidas na atividade do cultivo.

- A tecnologia já existe e a Cadeia da Ostreicultura do Estado do Pará precisa começar a depurar as ostras do Cultivo antes da venda. Depuração é sinônimo de qualidade para cadeias produtivas de ostras no Brasil e no Mundo.

- Nos próximos anos a cadeia produtiva precisa se preocupar com problemas relacionados à logística de transporte e embalagem; diversificação de esforços de marketing adequados; adoção de percepção de risco e estratégias de gestão além de aumentar investimentos e parcerias com empresas privadas e institutos de ensino superior.

- A “Rede Nossa Pérola” possui uma relação direta com as associações e conforme o regimento interno da “Rede” as instituições de ensino superior (IES´s) são convidadas quando for necessário.

Capítulo 2

Physical-chemical characteristics of the water at oyster culture units on the Amazon macrotidal mangrove coast of northern Brazil.

Características físico-químicas da água nos cultivos de ostras na costa de manguezal amazônica do norte do Brasil.

- Entre as unidades de cultura de ostra no Estado do Pará, as características da qualidade da água são principalmente adequadas para o crescimento de juvenis (maior salinidade, maior pH e maior profundidade) em ASAPAQ e AGROMAR, ou para colheita de sementes de ostras em ambiente natural (menor salinidade e pH mais baixo) na AQUAVILA no rio Iririteua e AGRONAM no rio Mocajuba.
- A AQUAVILA domina a comercialização de sementes, mas AGRONAM começou a se dedicar, em pequena escala, a essa atividade. As localidades de São Caetano de Odivelas (ASSOPEF e AMPAP) e Maracanã (AAPPNS) apresentam baixo nível produção de ostras adultas, mesmo com características adequadas da água.
- No cultivo de ostras em Maracanã (AAPPNS) a baixa produção de ostras não está relacionada às características da água do cultivo e sim com o baixo nível de envolvimento dos membros da associação.

<u>Capítulo 3</u>

Settlement, growth and commercialization of native oysters *Crassostrea gasar* cultivated in Amazonian mangrove estuaries.

Assentamento, crescimento e comercialização de ostras nativas Crassostrea gasar cultivadas em estuários de manguezais amazônicos.

- Podemos concluir que a Associação AQUAVILA em Curuçá possui condições adequadas para a captação de sementes de ostras (*Crassostrea gasar*) em ambiente natural e que essa captação está aumentando a cada ano conforme as estatísticas oficiais e que a espécie exótica (*Crassostrea sp*.) aparece em pequena quantidade no período do verão.

- O cultivo de ostras da AGROMAR é o ambiente mais adequado para o crescimento com baixos valores de mortalidade e elevados valores de sobrevivência.

- Na comercialização de ostras de tamanho comercial do tipo Baby e Média, observamos que os tamanhos não são respeitados, ou seja, o grupo AQUAVILA vende ostras acima do tamanho proposto e a AGROMAR vende de acordo com os tamanhos. A sugestão é que no momento da comercialização, cada grupo deve utilizar equipamentos que comprovem para o consumidor que está comprando. A AQUAVILA vende ostras acima do tamanho proposto onde quem sai ganhando é o consumidor. A AGROMAR vende de acordo com os tamanhos propostos pela comercialização.

- Conforme os resultados apresentados, podemos inferir que o peso de cada dúzia pode seguir o padrão adotado pelo principal produtor de ostras do Brasil que é o Estado de Santa Catarina (1 dúzia equivale a 1 kg).

- A concha da ostra é um resíduo gerado a partir do cultivo que não está sendo utilizado atualmente e observamos que a variação anual é de 77% é concha na ostra Baby e 80% é concha na ostra média.

AÇÕES DE EXTENSÃO DA TESE

Ações de Extensão da Tese

No período de desenvolvimento dessa pesquisa, muitas outras atividades foram desenvolvidas tais como: cooperações institucionais regionais, nacionais e internacionais; participação em eventos científicos; entrevistas na mídia falada e escrita; exposições fotográficas; visitas técnicas nacionais e internacionais e além de muitas ações de diálogo permanente e transparente com as comunidades ribeirinhas envolvidas com o cultivo de ostras. Posso dizer que "*Aprendi ao longo desse tempo que para me aventurar a estudar esse mundo não bastava apenas observá-los de longe... Era necessário me deixar envolver pelas rotinas e tempos do trabalho. Ir lá... Viver também aquelas rotinas. Conhecer as pessoas, dividir a moradia, repartir a comida"* são essas atividades que trago relacionadas a seguir.

2013

Em outubro de 2013, participação de uma visita técnica na Reserva Extrativista do Mandira na cidade de Cananéia (SP), Unidade de Conservação de uso Sustentável do Instituto Chico Mendes de Conservação da Biodiversidade (ICMbio), visitando as áreas de engorda de ostras e a unidade de Depuradora da Cooperativa dos Produtores de Ostras (Cooperostra). Ao conhecer a estrutura do Instituto de Pesca do Estado de São Paulo em Cananéia (SP) e conversando com alguns pesquisadores, conheci a portaria de nº. 046 de 11 de dezembro de 1987 da Superintendência do Desenvolvimento da Pesca que determina um período do defeso e o tamanho de captura das ostras em ambiente natural. Essa legislação é a única do país que protege bancos naturais de moluscos.

2014

Participação da reunião da Rede de Sustentabilidade em Aquicultura em fevereiro de 2014 em Brasília nas dependências do extinto Ministério da Pesca e Aquicultura. Essa rede envolveu 35 pesquisadores e 20 colaboradores de 10 estados brasileiros. Estes pesquisadores são divididos em grupos para quantificar a sustentabilidade de 23 sistemas de produção aquícola. Um deles é um sistema artesanal de engorda de ostras no Estado do Pará.

Participação em uma mesa redonda intitulada *"Cultivo de ostras no Pará como produto da pesquisa e extensão universitária: da tradição do extrativismo à modernidade da produção*" no VI Congresso Brasileiro de Extensão Universitária que aconteceu em Belém/Pará em maio de 2014.

Em agosto de 2014, fui entrevistado na Rádio WEB da UFPA (Divulgando o conhecimento) pelo Prof. Dr. Joel Cardoso em Belém referente aos objetivos da proposta da pesquisa do Doutorado.

2015

Em outubro de 2015, participei de uma mesa redonda intitulada "Potencialidades para a produção na Malacocultura" onde apresentei a dinâmica da Cadeia Produtiva dos Cultivos de Ostras no Estado do Pará no XIX Congresso Brasileiro de Engenharia de Pesca em São Luís.

Em novembro de 2015 fui o terceiro brasileiro filiado à World Oyster Society (WOS), entidade sem fins lucrativos constituída em 2005 que têm como missão "Ser um instrumento de boa vontade, amizade e cooperação para todos os que têm alguma ligação com a pesquisa, produção e uso de ostra em qualquer lugar do mundo". Não existe nenhum custo de filiação e atualmente já existem quinze (15) brasileiros filiados. Conheci a entidade através da brasileira Darien Mizuta, pesquisadora da Universidade de Kyoto no Japão.

Maiores informações; http://www.worldoyster.org/index_e.html

2016

Em março de 2016, participei da I Mostra de Talentos da Universidade Federal do Pará (Campus de Bragança) promovido pela Diretoria de Extensão (Diex) com a exposição fotográfica "No ritmo da maré: cultivos de ostras no Nordeste Paraense" **(Anexo 04).** As fotos mostram os sete (7) cultivos de ostras no Nordeste Paraense, mostrando um dia de trabalho na vida dessas pessoas. O texto que apresenta a exposição é uma homenagem aos 10 anos dos cultivos de ostras no Estado do Pará (2006-2016).

Em agosto de 2016, recebi um convite para divulgar uma versão em inglês do texto no "No ritmo da maré: cultivos de ostras no Nordeste Paraense" (The rhythm of the tide: oyster cultivation in northeastern Pará) no Boletim Electronico El Bohio, vol. 6, nº 6, agosto de 2016. Publicado en Cuba. ISSN 2223-8409.

Maiores informações: http://portalelbohio.es/

Em setembro de 2016 foi publicado uma foto do cultivo de ostras na comunidade de Lauro Sodré/Curuçá, de minha autoria na capa do Boletim Electronico El Bohio, vol. 6, nº 8.

Em setembro de 2016 fiz uma visita técnica na cadeia da Ostreicultura na cidade de Aveiro em Portugal. No período da visita técnica fui recebido pelo pesquisador da Universidade de Aveiro (UA), Prof. Dr. Ricardo Calado. Visitei os cultivos de ostras na Ria de Aveiro e conheci o novo Laboratório de Investigações Marinhas (Ecomare). No período da visita conheci as dependências do Departamento de Biologia da Universidade de Aveiro e conversamos sobre futuras parcerias no âmbito da temática da Aquacultura Marinha com ênfase na produção de ostras com o Laboratório de Moluscos da UFPA/IECOS/Bragança. Maiores informações: http://www.cesam.ua.pt/ricardocalado

2017

Em janeiro de 2017 foi publicado uma foto do cultivo de ostras de Nazaré do Mocajuba/Curuçá de minha autoria na capa do Boletim Electronico El Bohio, vol. 7, nº 1.

No dia 03 de março de 2017 submeti um ensaio fotográfico com quinze (15) fotos de minha autoria mais o texto no Ritmo da Maré para um dossiê "Questões Socioambientais e Etnobiodiversidade" na Amazônica: Revista de Antropologia, periódico científico do Programa de Pós-Graduação em Antropologia da UFPA. Atualmente o status desse ensaio é "em edição".

Publicação no site “The World Oyster Society (WOS)” de fotos dos cultivos de ostras no Brasil, mais especificamente de cultivos do Nordeste do Pará de minha autoria. No site da WOS existe uma área de divulgação de fotos de cultivos de ostras pelo mundo. Até fevereiro de 2017 constava fotos de cultivos em dezesseis (16) países e o Brasil não constava nessa lista. As primeiras fotos do Brasil são dos cultivos de ostras no Estado do Pará no link abaixo:

http://www.worldoyster.org/oysterfarm/oyster%20farm_e.html#brazil

No dia 10 de abril de 2017 foi publicada a matéria intitulada *“Tese de professor do Campus de Bragança aborda cultivo de ostras no Nordeste do Pará”* no site da Universidade Federal do Pará através do link abaixo.

http://multicampi.ufpa.br/index.php?option=com_content&view=article&id=1389:2017-04-10-17-51-45

Ainda no mês de abril de 2017, fui entrevistado pelo jornalista Vito Gemaque do “Jornal O Liberal”, veículo no qual foi publicada a matéria “Ostras são alternativas para a Economia” (Jornal Liberal, caderno Poder/Dinheiro, 23 de abril de 2017).

ANEXOS

Anexo 1. E-mail de confirmação da submissão do manuscrito científico intitulado “Oyster culture on the Amazon mangrove coast: asymmetries and advances in an emerging sector” **(Capítulo 1)**, enviado ao periódico científico ***Reviews in Aquaculture*** para avaliação e publicação.

2017-6-16 Gmail - Reviews in Aquaculture - Account Created in Manuscript Central

Gmail **Dioniso Sampaio <sampaio.ds@gmail.com>**

Reviews in Aquaculture - Account Created in Manuscript Central
1 mensagem

Reviews in Aquaculture <onbehalfof+RAQ+wiley.com@manuscriptcentral.com> 16 de junho de 2017 10:55
Responder a: RAQ@wiley.com
Para: sampaio.ds@gmail.com

16-Jun-2017

Dear Mr. Sampaio:

A manuscript titled Oyster culture on the Amazon mangrove coast: asymmetries and advances in an emerging sector (RAQ-06-17-0053) has been submitted by Mr. Dioniso Sampaio to Reviews in Aquaculture.

You are listed as a co-author for this manuscript. The online peer-review system, Manuscript Central, automatically creates a user account for you. Your Reviews in Aquaculture - Manuscript Central account information is as follows:

Site URL: https://mc.manuscriptcentral.com/raq
USER ID: sampaio.ds@gmail.com
PASSWORD: For security reasons your password is not contained in this email. To set your password click the link below.

https://mc.manuscriptcentral.com/raq?URL_MASK=1f2bc0fbfba5487f8876e2548d9ac817

You can use the above USER ID and PASSWORD (once set) to log in to the site and check the status of papers you have authored/co-authored. Please log in to https://mc.manuscriptcentral.com/raq to update your account information via the edit account tab at the top right.

Thank you for your participation.

Sincerely,
Reviews in Aquaculture Editorial Office

Anexo 2. E-mail de confirmação da submissão do manuscrito científico intitulado “Physical chemical characteristics of the water at oyster culture units on the Amazon macrotidal mangrove coast of northern Brazil (**Capítulo 2)**, enviado ao periódico científico ***Acta Amazonica*** para avaliação e publicação.

2017-6-16 Gmail - Acta Amazonica - Manuscript ID AA-2017-0194

Gmail

Dioniso Sampaio <sampaio.ds@gmail.com>

Acta Amazonica - Manuscript ID AA-2017-0194

1 mensagem

Acta Amazonica <onbehalfof+eic-acta+inpa.gov.br@manuscriptcentral.com> 16 de junho de 2017 16:17
Responder a: eic-acta@inpa.gov.br
Para: sampaio.ds@gmail.com
Cc: sampaio.ds@gmail.com, mdelssantos@yahoo.com.br, tagliaro@ufpa.br, beasley@ufpa.br

16-Jun-2017

Dear Prof. Sampaio,

Your manuscript entitled "Physical-chemical characteristics of the water at oyster culture units on the Amazon macrotidal mangrove coast of northern Brazil" has been submitted to Acta Amazonica.

Your manuscript ID is AA-2017-0194.

In due time the Editorial Office will inform you the Editor´s Decision.

Please mention the above manuscript ID in all future correspondence.

If there are any changes in your street address or e-mail address, please log in to ScholarOne Manuscripts at https://mc04.manuscriptcentral.com/aa-scielo and edit your user information as appropriate.

You can also view the status of your manuscript at any time by checking your Author Center after logging in to https://mc04.manuscriptcentral.com/aa-scielo.

Thank you for submitting your manuscript to the Acta Amazonica.

Sincerely,

Acta Amazonica Editorial Office

Anexo 3. E-mail de confirmação da submissão do manuscrito científico intitulado "Settlement and growth of native oysters *Crassostrea gasar* cultivated in Amazonian mangrove estuaries" (**Capítulo 3)**, enviado ao periódico científico ***Pesquisa Agropecuária Brasileira*** para avaliação e publicação.

2017-6-17 Gmail - [PAB] Agradecimento e registro da Submissão

Gmail **Dioniso Sampaio <sampaio.ds@gmail.com>**

[PAB] Agradecimento e registro da Submissão
1 mensagem

Pesquisa Agropecuária Brasileira - PAB <sct.pab@embrapa.br> 17 de junho de 2017 18:07
Para: Professor Dioniso de Souza Sampaio <sampaio.ds@gmail.com>

Professor Dioniso de Souza Sampaio,

Agradecemos a submissão e comunicamos o recebimento do trabalho "Settlement, growth and commercialization of native oysters Crassostrea gasar cultivated in Amazonian mangrove estuaries" pela revista Pesquisa Agropecuária Brasileira. Informamos que é possível acompanhar o progresso do documento dentro do processo editorial, basta logar no sistema em:

URL do Manuscrito:
http://seer.sct.embrapa.br/index.php/pab/author/submission/26048
Login: sampaiods

Informamos que, diante do grande número de trabalhos recebidos para publicação (média de 110 por mês), os trabalhos estão sendo analisados pela Comissão Editorial da revista, antes de serem submetidos à assessoria científica.

Nessa análise consideram-se os seguintes aspectos, entre outros: escopo, apresentação do artigo segundo as normas da revista; formulação do objetivo de forma clara; clareza da redação; fundamentação teórica; atualização da revisão da literatura; coerência e precisão da metodologia; discussão dos fatos observados em relação aos descritos na literatura; resultados com contribuição significativa; qualidade das tabelas e figuras; e, finalmente, originalidade e consistência das conclusões.

Após a aplicação desses critérios, caso o número de trabalhos aprovados ultrapasse a capacidade de publicação mensal (20 por mês), é aplicado o critério da *relevância relativa*. Segundo esse critério, os trabalhos com contribuição mais significativa para o avanço do conhecimento científico são aprovados. Esse critério é aplicado apenas aos trabalhos que atendam aos requisitos de qualidade, mas que, por excederem a capacidade de publicação mensal da revista, não podem ser todos aprovados. Por esse mesmo motivo, informamos que não aceitamos pedido de reconsideração.

Em caso de dúvidas, envie suas questões para este correio eletrônico.
Agradecemos por escolher a revista PAB para publicar seu trabalho.

Pesquisa Agropecuária Brasileira - PAB
Pesquisa Agropecuária Brasileira

Pesquisa Agropecuária Brasileira
Embrapa Informação Tecnológica
http://seer.sct.embrapa.br/index.php/pab

Aviso de confidencialidade

Anexo 4. Texto de minha autoria divulgado em 2016 na I Mostra de Talentos da Universidade Federal do Campus de Bragança.

No ritmo da maré: cultivos de ostra no Nordeste Paraense.

Como profissional acompanho os cultivos de ostra no Estado do Pará há dez anos e posso dizer com certa propriedade que nesse universo o ritmo é outro. Bem diferente daquele que levamos em terra firme.

Do cultivo ao prato o caminho percorrido é longo ...

A maré estabelece o horário de trabalho e aí não adianta ter pressa, pois nada se pode fazer a não ser esperar que as águas ditem o ritmo das coisas.

Os momentos de espera são longos...

E no intervalo do trabalho as vidas que se ali se encontram vão tecendo amizades no entrelace das lanternas e travesseiros. As madrugadas são preenchidas com conversa e fumaça dos cigarros enrolados e compartilhados por mãos calejadas.

De sol a sol o cultivo exige do trabalhador muita dedicação. O trabalho é duro, cansativo e o sol não dá trégua. O contato da água salgada com a pele queimada não refresca. Arde, assa, queima...

Aprendi ao longo desse tempo que para me aventurar a estudar esse mundo não bastava apenas observá-los de longe... Era necessário me deixar envolver pelas rotinas e tempos do trabalho. Ir lá... Viver também aquelas rotinas. Conhecer as pessoas, dividir a moradia, repartir a comida.

Os registros que fiz ao longo desse tempo são flagrantes do cotidiano de homens e mulheres que vivem do cultivo das ostras em diferentes localidades do Nordeste Paraense. São retratos que flagram as peculiaridades e a beleza de uma rotina de trabalho desafiadora e cansativa.

Paisagem, trabalho e pessoas se misturam deixando as marcas que humanizam minha pesquisa.

A esses trabalhadores meu respeito e gratidão.