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Maristela Casé Costa Cunha

A COMUNIDADE PLANCTÔNICA COMO INDICADORA DA QUALIDADE DA ÁGUA EM VIVEIROS DE CULTIVO DE CAMARÕES NO NORDESTE DO BRASIL

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Tese apresentada ao Programa de Pós-Graduação em Oceanografia da Universidade Federal de Pernambuco como parte dos requisitos para a obtenção do título de Doutor em Ciências na Especialidade Oceanografia.

Orientadora: Dra. Sigrid Neumann Leitão

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que sempre estiveram presentes nos
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"Nós somos madeira de lei que o cupim não rói".
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RESUMO

Uma doença de origem desconhecida que está ocorrendo no camarão marinho (*Litopenaeus vannamei*) em viveiros vem causando uma diminuição da sobrevivência dos organismos cultivados. A doença chamada de Mionecrose Infecciosa (IMN) foi confirmada em 14 viveiros localizados nos estados do Piauí, Maranhão, Ceará e Rio Grande do Norte, Nordeste do Brasil. Para contribuir no conhecimento desta doença e sua relação com produtividade dos camarões dos viveiros, o plâncton das 14 fazendas foram estudados entre outubro/2003 e novembro/2003. Os viveiros foram caracterizados como de alta densidade (>30 PL/m^2). Em cada fazenda amostrada foram estudadas três estações (captação de água; viveiro 1 – sem indício da virose; viveiro 2 – com indício de vírus). As amostras de água para o fitoplâncton foram coletadas com garrafa plástica de 100 mL e as amostras preservadas em solução de Lugol 1%. As amostras de zooplâncton foram obtidas com uma rede de plâncton padrão com 1 m de comprimento, boca com 30 cm diâmetro e malha com abertura de 50 micrômetros; 3 minutos de arrasto subsuperficial foram realizados em cada estação. As amostras foram preservadas em uma solução de formalina/água do mar a 4%. O fitoplâncton esteve representado por 51 táxons infragenéricos com concentrações de 365,218 ± 416,615 cel.mL^{-1} a 1,961,675 ± 3,160,172 cel.mL^{-1}. As diatomáceas contribuíram com quase 70% e as altas densidades devidas a florações de Cyanophyta, principalmente *Pseudanabaena* cf. *limnetica* Quarenta táxons zooplanctônicos foram registrados e essencialmente compostos por espécies marinhas eurialina e suspensívoras. O zooplâncton variou de 972 ± 209 ind.m^{-3} de 4,235 ± 2,877 ind.m^{-3}. Copepoda dominou (45%) seguido por Protozoa (18%), Rotifera e larvas de Mollusca (com 12%, cada). A entrada de nutrientes afetou a densidade e composição do plâncton. A dominância de diatomáceas e copépodos foi substituída por cianobactérias, protozoários e rotíferos quando a concentração de nutrientes aumentou ao longo do cultivo, indicando que a estrutura do plâncton foi afetada por condições eutróficas. Contudo, a qualidade ambiental dos viveiros é pobre, a comunidade planctônica indica que o ambiente é resiliente, possibilitando o retorno a uma condição melhor, desde que boas práticas de manejo sejam empregadas.

Palavras-chave: Fitoplâncton, zooplâncton, aqüicultura, camarão, *Litopenaeus vannamei,* Brasil

ABSTRACT

A disease of unknown origin is occurring in marine shrimp (*Litopenaeus vannamei*) ponds causing a decrease in the survival rate of cultured organisms. The disease named Idiopathic Abdominal Necrosis (IAN) have been confirmed in ponds from 14 farms located in Piauí, Maranhão, Ceará and Rio Grande do Norte states, Northeastern Brazil. In order to contribute to the knowledge of this disease and its relation to the performance of the shrimps in the ponds, the plankton from 14 farms was studied from october/2003 to november/2003. The ponds were categorized in high stocking density (>30 PL/m^2). In each farm sampling were made in tree stations (intake water point; pond 1 – without viruses indicia; pond 2 – with viruses indicia). Water samples for phytoplankton were collected with a 100 mL plastic bottle and samples preserved with 1% Lugol's iodine solution. Zooplankton samplings at each station was conducted with a standard plankton net with 1 m length, 30 cm mouth diameter and mesh size of 50 micrometers; 3 minutes horizontal subsurface hauls were made at each site. Samples were preserved in a 4% buffered formalin/seawater solution. Phytoplankton consisted of 51 infrageneric taxa with concentrations ranging from 365,218 ± 416,615 cell.mL-1 to 1,961,675 ± 3,160,172 cell.mL-1. Diatoms contributed to almost 70% and high densities resulted from Cyanophyta blooms, mainly *Pseudanabaena* cf *limnetica*. Forty zooplankton taxa were registered and essentially composed of typical marine euryhaline species and suspension-feeders. Zooplankton varied from 972 ± 209 ind.m^{-3} to 4,235 ± 2,877 ind.m^{-3}.Copepoda dominated (45%) followed by Protozoa (18%), Rotifera and Mollusca larvae (with 12%, each). Enhanced nutrient input affected plankton density and composition. Diatoms and copepods dominance were replaced by cyanobacteria, protozoan and rotifers as nutrient concentrations increased with the cultured period, indicating that plankton structure was affected by eutrophic conditions. Although environmental quality ponds was poor the plankton community indicates that the environment is resilient being possible to return to a better condition, since good management practices will be employed.

Key-words: phytoplankton, zooplankton, aquaculture, shrimp, *Litopenaeus vannamei,* Brazil

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1 Introdução

A Aqüicultura é o processo de produção em cativeiro, de organismos que dependem da água para a realização total ou parcial de seu ciclo de vida, em qualquer estágio de desenvolvimento. Segundo Nunes (2000), é o segmento responsável pelo aumento da oferta mundial do pescado, sendo este, a terceira fonte de proteína de origem animal. Dentro da Aqüicultura, o cultivo de camarões é a maior indústria em áreas tropicais e subtropicais no mundo, com uma produção corrente, em 2004, de 1.386.382 toneladas, sendo o camarão do Pacífico, *Litopenaeus vannamei* (Boone, 1931), a espécie mais importante cultivada nas Américas (PEDRAZZOLI *et al*., 1998; FAO, 2000). No Brasil, no ano de 2003, foram produzidas 90.190 toneladas de camarão, consolidando a posição de líder no Hemisfério Sul, sendo mais expressiva nos estados da região Nordeste, responsável por 85.852 toneladas, representando 95% da produção nacional (ROCHA *et al*., 2004).

A indústria da produção de camarões é regularmente e seriamente afetada por problemas ligados a degradação ambiental e patologias infecciosas (KAUTSKY *et al*., 2000; BACHÈRE, 2000). No Brasil, assim como em outros países nas Américas, a sustentabilidade na indústria do cultivo de camarões têm sido ameaçada por várias patologias (PINHEIRO *et al*., 2007). Em áreas costeiras do Piauí, Ceará, Maranhão, Rio Grande do Norte, Pernambuco e Paraíba, a Mionecrose Infecciosa (IMN) levou a uma mortalidade de 40 a 70% em cultivos de *L. vannamei*, além de atingir *L. stylirotris*, P. *monodon* e *Farfantepenaeus subtiltis* (LIGHTNER *et al*., 2004a; TANG *et al*., 2005). Esta enfermidade atinge o músculo estriado, glândulas e órgão linfóides (LIGHTNER *et al*., 2004a).

Dado o potencial dos impactos adversos e o alto valor econômico da carcinicultura nos trópicos, existe a necessidade de pesquisas com resultados que possam ser aplicados imediatamente num programa de manejo (PÁEZ-OSUNA, 2001). Com esse intuito e visando a identificação e caracterização da biodiversidade microbiológica dos viveiros de cultivo, além da identificação das características físico-químicas da água e do solo e da histopatologia dos camarões cultivados, como uma forma de contribuir para o conhecimento das causas que, direta ou indiretamente, têm relação com o desempenho dos camarões em cultivo, a ABCC (Associação Brasileira de Criadores de Camarão Cultivado) elaborou um Projeto de Pesquisa desenvolvido durante outubro/2003 a janeiro/2004. Foram realizadas amostragens de fitoplâncton, microfitobentos e zooplâncton, coletadas em viveiros localizados nos estados de Piauí, Ceará e Rio Grande do Norte, para o conhecimento das características quali-quantitativas das microalgas planctônicas e do bentos, como também dos organismos do zooplâncton, objetivando a identificação das condições ecológicas dos viveiros.

O plâncton tem um papel primordial na indústria de camarão cultivado, sendo uma fonte importante de nutrientes para os camarões (MARTINEZ-CORDOVA *et al*., 1998), que podem consumi-lo diretamente ou aderido aos detritos (MARTINEZ-CORDOVA *et al*., 2002), funcionando como um elo de ligação entre os nutrientes disponibilizados nos viveiros, através da adição de compostos químicos e da água captada, e os organismos que se localizam no topo da teia alimentar aquática.

Um bom monitoramento das condições dos viveiros pode ser derivado da observação de indicadores planctônicos, tais como sua biomassa, abundância e diversidade de espécies (BURFORD, 1997; PHILLIPS, 1998; PRIMAVERA, 1998). As alterações na composição de espécies, tamanho e estrutura das comunidades podem ser alteradas tanto por mudanças na carga de nutrientes, como pela predação e pastagem (HANSEN *et al*., 1994; STOLTE *et al*., 1994; INGRID *et al*., 1996; COTTINGHAM, 1999; MICHELI, 1999; ROELKE *et al*., 1999; SIPURA *et al*., 2003), constituindo uma cascata na cadeia alimentar, alterando a dinâmica de consumo, e assim o fluxo de carbono e energia total do sistema. Podendo, portanto, limitar a produtividade dos camarões (JOHNSTON *et al.*, 2002).

Em viveiros utilizados para piscicultura, a combinação de dados físico-químicos e de informações, em longo prazo, sobre o plâncton, são apontadas como necessárias para a caracterização completa da qualidade da água (HOSSAIN *et al*., 2007). De modo a complementar o monitoramento da qualidade da água nos viveiros de cultivo, o fito e zooplâncton podem ser excelentes indicadores das condições ambientais e da saúde dentro dos viveiros, pois eles são sensíveis às variações na qualidade da água. Eles respondem a diminuição de oxigênio dissolvido, altos níveis de nutrientes, contaminação por substâncias tóxicas, baixa qualidade ou escassez de alimento ou predação.

Considerando a importância sócio-econômica da cadeia produtiva do camarão, a necessidade de informações sobre as causa que levam a diminuição da qualidade da água nos viveiros acometidos por patologias no nordeste brasileiro e o valor da comunidade planctônica como ferramenta de biomonitoramento, o plâncton amostrado nos viveiros de cultivo do camarão do Pacífico, *Litopenaeus vannamei* (Boone, 1931), foi o objeto da presente tese. Esta tem a finalidade de analisar comunidade planctônica nos referidos viveiros fornecendo informações para que a mesma possa ser utilizada como uma ferramenta adicional no monitoramento da qualidade da água desses ambientes.

2 Base Conceitual

Mais de 50 países possuem fazendas de camarão, destacando-se o Equador, Tailândia, China, Malásia, México, Peru e Brasil (BEVERIDGE, 1996). No Nordeste brasileiro, a carcinicultura apresenta algumas características que trazem vantagens preponderantes, como a não dependência de água doce, em qualquer fase do seu ciclo produtivo; o uso de áreas planas costeiras (salitradas) improdutivas e a utilização de mão-de-obra sem exigência de qualificação profissional (ROCHA, 2005). Contudo, a carcinicultura, como qualquer outra atividade de produção, pode causar impacto ambiental, motivo pelo qual é caracterizada como “atividade potencialmente poluidora” no cadastro nacional de atividades poluidoras do IBAMA (PEREIRA, 2004). Os dois tipos de sistemas de produção existente para esta atividade, extensivo com sistemas integrados e praticado por muitos anos em alguns locais, e intensivo, sistema “fechado” que permite a fazenda um melhor controle ambiental, podem ser prejudiciais a sustentabilidade ambiental. (RÖNNBÄCK, 2002).

Segundo a Resolução do CONAMA Nº 01 de 23/01/86, impacto ambiental é qualquer alteração das propriedades físicas, químicas e biológicas do meio ambiente, causada por qualquer forma de matéria ou energia resultante das atividades humanas que, diretamente, afetem: (I) a saúde, a segurança e o bem-estar da população; (II) as atividades sociais e econômicas; (III) a biota; (IV) as condições estéticas e sanitárias do meio ambiente; (V) a qualidade dos recursos ambientais. Há de se destacar, entretanto, que o conceito de impacto ambiental não se refere unicamente ao meio ambiente biológico. Na verdade, o mesmo vem a ser o resultado do efeito das atividades humanas no conjunto composto pelos níveis físico, biológico e socioeconômico (ARANA, 1999).

São vários os fatores que caracterizam a carcinicultura como uma atividade impactante: a localização das fazendas, o manejo e uso de tecnologia durante a operação dos viveiros, o cultivo superficial e escala da produção, a falta de um monitoramento adequado; e capacidade de depuração do corpo aquático receptor dos efluentes (ENG *et al*., 1989; NAYLOR *et al*., 1998; PÁEZ-OSUNA, 2001). Além disso, a disseminação de sementes, a introdução de espécies exóticas e doenças, o uso da água, suplementação alimentar, aumento dos nutrientes, e utilização de compostos químicos e antibióticos utilizados no cultivo causam impactos (RÖNNBÄCK, 2002). Estes, segundo o autor, podem ser diretos, quando há liberação de substâncias químicas tóxicas que levam a eutrofização, a transferência de doenças e parasitas para o ambiente natural, e a introdução de material genético exótico no ambiente, ou indiretos, através da perda do habitat e nicho, e alterações na teia alimentar.

Considerar a indústria de cultivo de camarões uma atividade geradora de impacto ambiental justifica-se, ainda, pelo fato de que nos últimos 40 anos sua expansão devastou praticamente metade dos manguezais do território brasileiro com o objetivo de atender a demanda dos países desenvolvidos (COELHO JÚNIOR, NOVELLI, 2000). Por conseqüência, ocorreu a diminuição da qualidade da água nos viveiros e da imunidade dos camarões (JOHNSTON *et al*., 2002; BOYD, 2003).

De fato, a intensificação da aqüicultura gera mais demanda de água, mais fertilizantes, mais alimento industrializado e mais produtos veterinários que são eventualmente descartados no meio ambiente. Em vários locais, caracterizados pela renovação de água por filtração semanal, a capacidade de dispersão dos efluentes não é eficiente o bastante para proteger as fazendas do seu próprio rejeito (PAQUOTTE *et al*., 1998).

A preocupação com os impactos gerados pela indústria de cultivo de camarões foi apontada por Barnabé (1990), quando este alertou para a descarga excessiva ou indiscriminada da matéria orgânica acumulada nos efluentes dos viveiros, que traz sérios danos à própria atividade, promove alterações das características físico-químicas da água (temperatura, oxigênio dissolvido e conteúdo de sais dissolvidos), e ao ambiente do entorno dos tanques escavados após a saída da água do cultivo. Este tipo desequilíbrio nos níveis de matéria orgânica (material fecal e restos alimentares) pode agravar alguns fenômenos como florações de microalgas e anoxia do ambiente, bem como de aumentar a eutrofização da água, colocando em perigo o desenvolvimento das espécies cultivadas e do restante do meio.

No corpo receptor, efeitos como a depleção de oxigênio, diminuição da penetração de luz devido aos sólidos suspensos, hipernitrificação da macrofauna bentônica e eutroficação da água, podem ocorrer. O fósforo oriundo dos efluentes dos cultivos, por exemplo, é identificado como um dos nutrientes que contribuem para a degradação ambiental (PAN *et al.*, 2005).

Uma das conseqüências das modificações nas condições físico-químicas da água no cultivo de camarões cultivados são as enfermidades, que incluem doenças infecciosas, causadas por vírus, ricketsias, bactérias, fungos e metazoários, bem como doenças não-infecciosas, que também têm grande importância na indústria, causando desequilíbrio ambiental e nutricional extremos, intoxicações e modificações genéticas (LIGHTNER, REDMAN, 1998). Contudo, vírus, bactérias e fungos vêm se destacando como causadores de enfermidades (BACHÈRE, 2000; DESTOUMIEUX-GARZÓN *et al.*, 2001; BURGENTS *et al.*, 2004).

Epidemias causadas por doenças virais levaram a diminuição da produção anual na Ásia. Em países com elevada produção, como a Tailândia, a presença de patógenos como o vírus da mancha-branca (WSSV), vírus da cabeça amarela (YHV), parvovírus da hepatopancreatite (HPV) e o *Baculovírus monodon* (MBV) nos cultivos de *P. monodon*, vírus Taura e vírus que causam infecções hipodérmicas e hematopoiéticas (TSV) em *L. vannamei*, vêm causando perdas significativas nos cultivos (FLEGEL, 2006). No Brasil e em outros países nas Américas, a sustentabilidade na indústria do cultivo de camarões tem sido ameaçada por várias patologias, dentre elas a Síndrome do vírus Taura (TSV), vírus da mancha branca (WSSV) e vírus da necrose idiopática (IHHNV) (PINHEIRO *et al.*, 2007), entre outros.

De acordo com Nunes e Martins (2002), inúmeros fatores ambientais podem desencadear um processo infeccioso nos camarões marinhos. Temperaturas e pH extremos, baixas concentrações de oxigênio dissolvido, mudanças abruptas na salinidade e presença de substâncias tóxicas são elementos associados a um desequilíbrio no ambiente. A propagação de bactérias patógenas oportunistas (*Vibrio* spp., *Aeromonas* spp.), a proliferação de protozoários (*Zoothamnium* spp. e gregarinas), a captação de água contaminada, a aquisição de pós-larvas com alta carga viral e a presença excessiva de microalgas (dinoflagelados e cianobactérias) também geram efeitos deletérios na saúde dos camarões.

Outro problema é a utilização de substâncias químicas na carcinicultura, com objetivo de aumentar quali-quantitativamente a produção. Estas também influenciam a qualidade da água dos viveiros e, conseqüentemente nos efluentes lançados no meio. Para Páez-Osuna (2001) o uso de substâncias químicas na carcinicultura é pequeno em comparação com a agricultura ou outras atividades econômicas. Todavia, várias formulações químicas e biológicas são aplicadas na água e sedimentos dos viveiros ou incorporadas à dieta dos camarões.

Baseadas em suas ações, os produtos usados nas fazendas podem ser classificados em nos seguintes grupos (PRIMAVERA *et al.*, 1993):

1. Terapêuticos e desinfectantes (iodo, formalina, oxitetraciclina, clorafenicol).
2. Condutores de água e sedimento.
3. Decompositores da matéria orgânica (bactérias e preparações enzimáticas).
4. Algicidas e peixecidas (compostos de cobre, saponina).
5. Promotores do crescimento de fitoplâncton (fertilizantes orgânicos e inorgânicos).
6. Aditivos nutricionais (vitaminas, minerais, hormônios).

As substâncias mais comuns usadas nos viveiros são os fertilizantes e adubos, as demais substâncias são usadas com menos freqüência (BOYD, MASSAUT, 1999). Ainda assim, o aumento do uso de antibióticos no cultivo intensivo tem levantado o interesse sobre os possíveis efeitos de sua liberação no ambiente adjacente, cogitando o aumento da resistência de patógenos (PÁEZ-OSUNA, 2001).

Normalmente, as fazendas de cultivo de camarão adotam como estratégia de manejo a estocagem das pós-larvas nos tanques-berçário, para aclimatá-las antes de iniciar o processo de engorda propriamente dito. Nessa fase, as pós-larvas são alimentadas com rações específicas ou muitas vezes trituradas. Independente da qualidade e ou da origem da dieta utilizada, grande quantidade de ração é ofertada, o que propicia a sua perda e conseqüentemente a sua decomposição, ocasionando deterioração e comprometimento da qualidade da água (SILVA, MENDES, 2006).

Dentro do cultivo de camarões a alimentação é uma das operações que demanda maior custo, pois uma formulação da ração desequilibrada pode contribuir com a deteriorização da qualidade da água (MARTINEZ-CORDOVA *et al.*, 2002). Dentro desta alimentação, os organismos vivos constituem uma fonte importante de nutrientes para os camarões (MARTINEZ-CORDOVA *et al*., 1998).

O alimento natural, constituído pelo fito e zooplâncton, tem uma significativa contribuição na melhoria da qualidade da água. Martinez-Cordova *et al*. (2002) citam que o fitoplâncton não é diretamente consumido pelos camarões, mas pode ser ingerido aderido aos detritos. A abundância de outras comunidades, tais como o zooplâncton e o bentos dependem da produtividade do fitoplâncton. Alguns organismos do zooplâncton e bentos são efetivamente consumidos pelos camarões, e contribuem significantemente para sua nutrição (ALLAN *et al*., 1995; SHUSHEHCHIAN, YUSSOF, 1999). O trabalho de Anderson *et al.*

(1987) revelou que esta contribuição pode representar mais de 75% das necessidades nutricionais destes organismos.

Algumas estratégias tem sido usadas para promover o crescimento da biota nos viveiros, sendo a fertilização uma prática comum para manter a produtividade do fitoplâncton (DE LA LANZA, MARTINEZ-CORDOVA, 1998). Para aumentar a abundância dos organismos zooplanctônicos, alguns cultivadores introduzem “promotores de zooplâncton” nos viveiros, constituídos de fardos de alfafa fermentada. Para promover a abundância de organismos bentônicos são usados fertilizantes orgânicos enriquecidos (MARTINEZ-CORDOVA *et al.*, 2002).

Estas práticas, assim como os demais impactos antrópicos, influenciam a estrutura (abundância de organismos, diversidade, etc.) e função dos ecossistemas receptores, sendo uma das principais conseqüências o processo de eutrofização que pode transformar áreas de circulação restrita de água, como os viveiros, em ambientes altamente anóxicos (MOSER *et al.* 2004). É uma preocupação real dos criadores o estado da qualidade da água nos viveiros, mesmo ocorrendo à adição de inúmeras substâncias químicas, como as citadas anteriormente. Para este monitoramento são utilizados apenas os fatores hidrológicos da água.

Para o controle do impacto ambiental causado pela aqüicultura no Brasil, o Conselho Nacional do Meio Ambiente (CONAMA) normatizou os níveis mínimos aceitáveis de qualidade da água a ser alcançados ou mantidos, em criações de espécies aquáticas destinadas à alimentação humana, através da Resolução N.º 20, de 18/06/1986. O pH, nitrogênio total, demanda bioquímica de oxigênio (DBO) e oxigênio dissolvido, são os parâmetros estabelecidos para o controle dos efluentes.

Em 1997, foi criada no encontro da Sociedade Mundial de Aqüicultura, a *Global Aquaculture Alliance* (GAA), uma entidade sem fins lucrativos com o objetivo de representar a indústria da aqüicultura em nível internacional, promovendo-a ambientalmente responsável.

Dentre as suas ações, determinou limites iniciais e metas a serem alcançadas para o controle dos efluentes derivados de viveiros da aqüicultura. Parâmetros como, pH, sólidos totais e suspensos, fósforo total, amônia nitrogenada total, DBO e oxigênio dissolvido, passaram a serem monitorados com seus níveis recomendados à água enquadrada na classe 7 (BOYD, GOUTIER, 2000).

Em decorrência aos parâmetros exigidos pela legislação e da necessidade de manutenção da produtividade, os estudos referindo-se a qualidade da água para o cultivo de camarões estão, em sua grande maioria, relacionados a parâmetros físico-químicos, como as concentrações de sólidos em suspensão (matéria orgânica total e particulada, clorofila a) e nutrientes (fosfato, nitrato e amônia), reafirmando a importância dos mesmos para a biota dos viveiros (THAKUR, LIN, 2003).

Entretanto, Johnston *et al.* (2002) consideram o plâncton e bentos, por formarem a base da cadeia alimentar nos viveiros, particularmente importantes, pois em alguns casos, limitam a produtividade dos camarões. Em viveiros utilizados para piscicultura, a combinação de dados físico-químicos e de informações, em longo prazo, sobre o plâncton, são apontadas como necessárias para a caracterização completa da qualidade da água (HOSSAIN *et al.*, 2007).

De fato, o plâncton funciona como um elo de ligação entre os nutrientes disponibilizados nos viveiros, através da adição de compostos químicos e da água captada, e os organismos que se localizam no topo da teia alimentar aquática. As alterações na composição de espécies, tamanho e estrutura das comunidades podem ser alteradas tanto por mudanças na carga de nutrientes (*Bottom-up controls*), como pela predação e pastagem (*Top-down*) (HANSEN *et al.*, 1994; STOLTE *et al.*, 1994; INGRID *et al.*, 1996; COTTINGHAM, 1999; MICHELI, 1999; ROELKE *et al.*, 1999; SIPURA *et al.*, 2003), constituindo uma cascata na cadeia alimentar, alterando a dinâmica de consumo, e assim o fluxo de carbono e energia total do sistema. Isto é portanto crítico no melhor entendimento das ligações entre a carga de nutrientes para as águas costeiras e a resposta do ecossistema (MURREL, LORES, 2004).

De modo a complementar o monitoramento da qualidade da água nos viveiros de cultivo, o fito e zooplâncton podem ser excelentes indicadores das condições ambientais e da saúde dentro dos viveiros, pois eles são sensíveis às variações na qualidade da água. Eles respondem a diminuição de oxigênio dissolvido, altos níveis de nutrientes, contaminação por substâncias tóxicas, baixa qualidade ou escassez de alimento ou predação. Um bom monitoramento das condições dos viveiros pode ser derivado da observação de indicadores planctônicos, tais como sua biomassa, abundância e diversidade de espécies (BURFORD, 1997; PHILLIPS, 1998; PRIMAVERA, 1998). Sendo assim, a presente tese propõe-se a analisar as seguintes hipóteses:

H^0: O plâncton é uma ferramenta eficiente para o monitoramento da qualidade da água nos viveiros de cultivo de camarões do nordeste brasileiro.

H’: O plâncton não pode ser utilizado com uma ferramenta eficiente para o monitoramento da qualidade da água nos viveiros de cultivo de camarões do nordeste brasileiro.

3 A Carcinicultura no Nordeste do Brasil

No Brasil, a produção de camarão marinho foi iniciada na década de 70, no Rio Grande do Norte, com a criação do "Projeto Camarão" como alternativa para substituir a extração do sal. Concomitantemente, o Estado de Santa Catarina desenvolveu pesquisas de reprodução, larvicultura e engorda do camarão e conseguiu produzir as primeiras pós-larvas em laboratório da América Latina (ABCC, 2004).

Para Morais (2002) o Nordeste é a região brasileira em que se encontram as melhores condições para a carcinicultura devido às altas temperaturas, com variação anual em torno de 22 a 30^{o}C, e à relativa estabilidade climática. Essas condições estão ainda aliadas a uma ampla extensão de terras às margens do litoral, boa qualidade da água e disponibilidade de mão-de-obra barata, indicando um considerável potencial para a expansão da maricultura.

O desenvolvimento da carcinicultura no Brasil pode ser considerado em três fases. O período compreendido entre 1978 e 1984 caracterizou a primeira fase, onde predominou cultivos extensivos de baixa densidade de estocagem, reduzida renovação da água e uso da alimentação natural produzida no próprio viveiro. O Governo do Rio Grande do Note, com o apoio da Empresa de Pesquisas Agropecuárias do Rio Grande do Norte (EMPARN), importou animais da espécie *Penaeus japonicus* e reforçou o "Projeto Camarão", sistematizando e desenvolvendo trabalhos de adaptação da espécie exótica às condições locais (RABELO, 2006).

Os resultados favoráveis na adaptação de *P. japonicus* nos três primeiros anos dos trabalhos da EMPARN, em relação à reprodução e larvicultura e ao processo de crescimento e engorda, serviram de base para a mobilização dos mecanismos federais de incentivos e financiamentos à iniciativa privada da época. A realização em Natal, em setembro de 1981, do "I Simpósio Brasileiro Sobre Cultivo do Camarão" também teve papel decisivo na divulgação do desempenho da espécie importada do Japão e na implantação das primeiras fazendas de camarão no Nordeste. A decisão da Companhia Industrial do Rio Grande do Norte (CIRNE) de transformar parte de suas salinas em viveiros de camarão, estimulou outras iniciativas do setor privado.

Em 1984, a ocorrência de chuvas intensas, encerrando o longo período de estiagem na região, causou variações na salinidade das águas estuarinas, impossibilitando a maturação e reprodução dos cultivos de *P. japonicus*. Entre 1985/1986, já estava descartada a viabilidade de se desenvolver uma carcinicultura comercial com essa espécie.

A deficiência na tecnologia de produção de pós-larvas e de engorda da época forçou o cultivo extensivo das espécies nativas *L. schmitti* Burkenroad, *Farfantepenaeus subtilis* Pérez-Farfante e *F. paulensis* Pérez-Farfante (NUNES, PARSONS, 1999). A carcinicultura brasileira começou adquirir caráter tecno-empresarial, pois as improvisações praticadas até então começaram a ceder espaço ao profissionalismo e ao planejamento (ROCHA, MAIA, 1998). Contando com fazendas e laboratórios instalados e com experiência acumulada em procedimentos e práticas de produção, o sistema semi-intensivo começara a se estabelecer com a adoção de uma maior densidade de povoamento (de 4 a 6 camarões por m² de espelho d'água), taxas de renovação de água de 3% a 7% e alimento concentrado, iniciando a segunda fase da carcinicultura no Brasil.

Apesar dos avanços em aspectos importantes da maturação, reprodução e larvicultura das espécies nativas, bem como o desenvolvimento do manejo de água e de solos de fundo de viveiros, a produtividade dessas espécies não ultrapassou as médias de 400 a 600 $kg.ha^{-1}.ano^{-1}$. O desempenho insatisfatório estava relacionado às necessidades protéicas e a inexistência de alimentos concentrados que atendessem as exigências das espécies cultivadas.

Após o período de dez anos, a produtividade mostrava-se insuficiente para atender os custos de produção, comprometendo a rentabilidade do agronegócio levando à desativação de algumas grandes unidades produtivas da região. Nesta etapa, comprovou-se o potencial das espécies brasileiras e a necessidade de um programa de pesquisa básica e aplicada para melhor caracterizá-las e preservá-las bem como para investigar a fundo sua biologia e reprodução e seus requerimentos nutricionais.

A terceira fase da carcinicultura no Brasil, deu-se após o período de experimentações, quando pós-larvas e reprodutores do camarão branco do Pacífico (*L. vannamei*) foram introduzidos no país, em meados da década de 90 e os trabalhos de validação se acentuaram (WAINBERG *et al.*, 1998). O critério básico para a adoção da nova espécie foi o fato de ser a mesma já cultivada com êxito no Equador e Panamá e haver demonstrado capacidade de adaptação aos ecossistemas de diferentes partes do hemisfério ocidental.

Segundo Borghetti *et al*. (2003), a introdução e a utilização desta espécie representou um grande avanço para o país, provocando o desenvolvimento da cadeia produtiva da carcinicultura brasileira. A partir do momento em que laboratórios brasileiros dominaram a reprodução e larvicultura do *L. vannamei* e iniciaram a distribuição comercial de pós-larvas. As validações tecnológicas foram intensificadas no processo de adaptação do *L. vannamei* e a partir de 1995/1996 ficou demonstrada a viabilidade comercial de sua produção no País. Em 1998, fazendas de camarão marinho, estimadas em 113 unidades, cobriam 4.320 hectares e produziam 7.000 toneladas. Essas fazendas ocorrem predominantemente próximas a áreas úmidas costeiras, alcançando um tamanho entre 1 e 600 hectares e empregando aproximadamente 1 trabalhador para cada 3 ou 4 hectares (ROCHA, MAIA, 1998). Em 2001, o contingente de mão-de-obra empregada nesta atividade chegava a quase 60.000 pessoas, sendo que a produção nacional chegou a cerca de 40.000 toneladas, a área cultivada a 8.500 hectares e a produtividade média a mais de 4.700 $kg.ha^{-1}.ano^{-1}$.

A carcinicultura marinha é hoje uma das atividades agroindustriais mais atrativas economicamente, já que na década de 90, este setor vem registrando uma taxa média de expansão territorial da ordem de 20% ao ano (ROCHA, 2005). Segundo Rocha e Maia (1998), o desenvolvimento da carcinicultura no Brasil está concentrado na região Nordeste, com pequenas iniciativas nas regiões Norte, Sul e Sudeste. O autor ainda cita os estados produtores Rio Grande do Norte, Bahia, Ceará e Pernambuco na ordem de importância para o cultivo.

4 Caracterização dos cultivos de camarões

A Mionecrose Infecciosa atingiu principalmente os cultivos de camarões localizados na costa dos estados do Piauí, Ceará e Rio Grande do Norte. Com intuito de caracterizar as áreas atingidas pela enfermidade, é apresentado a seguir, algumas informações coletadas pela ABCC com relação ao tempo de cultivo, povoamento dos viveiros, peso dos camarões na despesca e sobrevivência dos mesmos nas regiões afetadas durante o ano de 2004, período de alta incidência da doença.

No litoral do Piauí, os cultivos de camarões apresentam ciclos de cultivo com em media 136 dias. Os viveiros caracterizam-se como densamente povoados, que variaram de 16,2 a 30,6 camarões.m^{-2} estocados no 3° e 2° trimestres, respectivamente, em 2004. Devido à presença da IMN, foi registrada a despesca prematura, com camarões a partir de 9 ou 10 g, chegando ao peso médio de 11,04 g ao final do mesmo ano. No aspecto geral, existem alterações positivas nas condições de sanidade dos animais nos últimos cultivos que estão sendo refletidos no aumento da sobrevivência, cuja media atual chega a 62,4% comparada com 52,4% em 2003.

No estado do Ceará a IMN ocorreu ao longo de todo litoral, entretanto, as regiões mais atingidas foram Camocim, Acaraú, Aracati, entre outras. Em Camocim, litoral norte do estado, que inclui as áreas de Coreaú e Guriú, os cultivos são caracterizados como de baixa densidade. A região de Coreaú apresentou uma média geral de povoamento de 31,2 camarões.m^{-2}. Algumas fazendas, contudo, utilizaram altas densidades, entre 50 e 60 camarões.m^{-2}. O tempo de cultivo foi de 158 dias no 1º trimestre, baixou para 153 dias no 2º trimestre, para 102 no 3º trimestre e voltou a subir no 4º trimestre, para 130 dias, com uma média final de 142 dias. O peso médio final foi de 12,54 g, com um peso médio mínimo de 10,35 g no 3° trimestre, e o máximo de 13,40 g no 2º trimestre. Esses dois parâmetros estiveram atrelados à taxa de sobrevivência, que diminuiu ao longo do ano. Por outro lado, a sobrevivência dos animais esteve inversamente relacionada ao aumento da densidade durante o ano. Enquanto no 4º trimestre a sobrevivência apresentou seu mínimo (40,46%), a densidade era de 34,9 camarões.m^{-2} alcançou os maiores valores. O período com maior índice de sobrevivência foi relatado no primeiro semestre, com 70,11% e menor densidade, 27,6 camarões.m^{-2}.

As fazendas localizadas na região de Guriú apresentaram densidades com mínimos e máximos de 35,8 e 42,0 camarões.m^{-2}, respectivamente. A sobrevivência média anual foi de 57,95%, variando de 42,13% no 1° trimestre de 2004 a 68,18% no 2° trimestre do mesmo ano. O peso médio anual variou de 9,73 a 14,28 g, com média de 12,90 g. O tempo de cultivo foi maior no 1º trimestre, 176 dias, diminuindo ao longo do ano, com mínimo de 104 dias no 3º trimestre.

Ainda no litoral norte do Ceará, mas na região do estuário do rio Acaraú, as fazendas apresentaram uma sobrevivência média com mínimo de 49,99% e máximo de 52,47%, com tempo de cultivo entre 135 e 147 dias. Durante este período a densidade populacional inicial adotada foi de 47,9 camarões.m^{-2} alcançando uma média de 69,4 camarões.m^{-2}, enquanto o peso de despesca vaiou de 10,43 a 12,23 g.

As fazendas localizadas no litoral leste, estuário do rio Jaguaribe, na região de Aracati, apresentaram sobrevivência média anual de 42,53%, variando de 32,58% no 4° trimestre de 2004 a 52,78% no 1° trimestre do mesmo ano. O tempo de cultivo para o mesmo período, apresentou uma média de 132 dias, variando de 116 no 3º trimestre a 142 no 4º trimestre. O peso final de despesca dos camarões cultivados apresentou uma média de 10,74 g, apresentando um valor mínimo de 10,28 g no 4° trimestre e máximo de 11,23 g no 1° trimestre. As densidades iniciais de cultivo utilizadas entre o 1° e o 4° trimestre de 2004 apresentaram valores médios mínimos e máximos de 72,6 e 55,7 camarões.m^{-2}, respectivamente, com uma redução significativa de 29,47% entre o 1° e o 3° trimestre.

Para o estado do Rio Grande do Norte, os dados apresentados são referentes aos estuários da região de Pendências, no litoral Norte. A sobrevivência média anual de 51,02%, variou de 37,57% no 4° trimestre de 2004 a 66,27% no 1° trimestre do mesmo ano. Os cultivos tiveram duração mínima de 142 dias, com 34,4 camarões.m^{-2}, no 3º trimestre e máximo de 174 dias de cultivo, com densidade de 44,6 camarões.m^{-2}, no 2º trimestre, com média de 159 dias. O peso médio final de cultivo, apresentado no ano de 2004 foi de 12,18g, variando de 11,03 a 13,21g nos 4° e 2° trimestres, respectivamente.

5 Material e Métodos

5.1 Coletas e análises do plâncton

As coletas foram realizadas em 14 fazendas de carcinicultura marinha localizadas no Ceará, Piauí e Rio Grande do Norte (Tabela 1) e povoadas por *Litopenaeus vannamei*, tendo sido as coletas realizadas nas seguintes condições:

a) em viveiros que apresentavam camarões com sintomas da Mionecrose Infecciosa;

b) em viveiros com camarões saudáveis e;

c) na captação de água da fazenda (estuário).

Tabela 1. Fazendas de cultivo de camarões marinhos no Nordeste do Brasil.

FAZENDAS (Cidade)	Latitude	Longitude
Ceará		
Promares, Aquafort e Samarisco (Camocim)	2º54'S	40º50'W
Papagaio e AS Marine (Acaraú)	2º50'S	40º07'W
Compescal, Cina e Vip Camarões (Aracati)	4º33'S	37º46'W
Piauí		
Camapi, Secom e Camarões do Brasil (Cajueiro)	2º55'S	41º20'W
Rio Grande do Norte		
Potiporã (*), MRG (*) e Aquática (*) (Pendências)	06º16'S	35º29'W

(*) Amostras coletadas durante as 2ª e 3ª campanhas.

Foram programadas três campanhas para coleta das amostras entre os meses de novembro e dezambro de 2003, conforme mostrado na Tabela 2.

Tabela 2. Campanhas realizadas nas fazendas de cultivo de camarões marinhos no Nordeste do Brasil.
Nov – Dez 2003

	Campanha		
Fazendas	1ª	2ª	3ª
Camarões do Brasil, Camapi e Secom	19/10	5/11	16/11
Promares, Aquafort e Samarisco	21/10	7/11	18/11
A. S. Marine e Papagaio	23/10	3/11	14/11
Compescal, Vip Camarões e Cina	25/10	8/11	19/11
Potiporã, Aquática e MGR.		20/11	22/11

As amostras de água para o fitoplâncton foram coletadas diretamente na superfície da água com frascos de plásticos (100 mL), devidamente etiquetados, e, imediatamente, preservadas com solução de Lugol 1%. Após as coletas, o material foi transportado sob refrigeração para o Laboratório de Ficologia da Universidade Federal Rural de Pernambuco, onde se realizaram as análises quali-quantitativas.

Para a identificação dos organismos fitoplanctônicos foram confeccionadas lâminas e observadas em fotomicroscópio Zeiss, ao qual estão acopladas ocular micrometrada e câmara clara. Os organismos foram identificados até o menor nível taxonômico possível, principalmente aqueles responsáveis por grandes florações, com base em bibliografia especializada, destacando-se Desikachary (1959), Dodge (1982), Anagnostidis, Komárek (1988), Silva-Cunha, Eskinazi-Leça (1990), Parra, Bicudo (1997). Quando necessário, os táxons foram ilustrados com fotomicrografias.

A contagem do fitoplâncton foi realizada pelo método de Utermöhl, (HASLE, 1978), utilizando-se microscópio invertido Zeiss, pertencente ao Laboratório de Ficologia da UFRPE. Para as contagens, foram utilizadas câmaras de sedimentação de 10 ml e as amostras sedimentadas por um período de 24 horas. Cada amostra foi corada com Rosa de Bengala, para facilitar a identificação das células, e as contagens realizadas em transecções, com aumento de 400X. Após as contagens, os valores foram transformados para cel.ml^{-1}, utilizando-se a fórmula proposta por Villafañe e Reid (1995).

A amostragem para o zooplâncton em cada estação foi realizada através de arrasto horizontal sub-superficial, com duração de 3 minutos, utilizando-se uma rede de plâncton com comprimento de 1 m, diâmetro de 30 cm e malha com 50 µm de abertura (Hydrobios, Kiel). O material coletado foi acondicionado em frascos plásticos (250 mL) identificados e preservados em solução de formol/água do mar a 4% tamponado. Após as coletas, as amostras foram transportadas para o Laboratório de Zooplâncton da Universidade Federal de Pernambuco para a identificação e contagem dos organismos.

Os táxons zooplanctônicos foram identificados até o menor nível taxonômico baseando-se na análise detalhada de 1 ml de cada amostra, retirada com auxílio de uma "Stempel-pipette" colocada em lâmina tipo Sedgwick-Rafter sob microscópio composto marca Zeiss. Foram contados 2 ml de cada amostra e feita a média aritmética. Além disso, cada amostra foi inspecionada na sua totalidade para verificar a presença de organismos patogênicos. Para a identificação dos organismos zooplanctônicos e obtenção de informações ecológicas, foram utilizadas, dentre outras, as seguintes bibliografias: Rose (1933), Tregouboff, Rose (1957), Björnberg (1981), Bougis (1974), Boltovskoy (1981; 1999) e Omori, Ikeda (1984).

Através da contagem do número de células ou indivíduos de um determinado táxon em um volume conhecido, foi calculado a Densidade específica. Esta foi expressa em $cel.mL^{-1}$, para o fitoplâncton, e $org.m^{-3}$, para o zooplâncton.

A partir dos resultados obtidos no cálculo da densidade a Abundância relativa, que indica a representatividade de cada taxa, foi estabelecida utilizando-se a fórmula a seguir, proposta por Lobo, Leighton (1986): Ar = N. 100/ Na, em que:

Ar = abundância relativa

N = número total de organismos de cada táxon na amostra analisada

Na = número total de organismos na amostra

Sendo os resultados expressos da seguinte forma:

> 70% - Dominante

≤ 70% e > 40 – Abundante

≤ 40% e > 10% - Pouco abundante

≤ 10% - Raro

Por meio do cálculo da Freqüência de ocorrência pode-se estimar o quanto cada táxon esteve presente no local analisado. Para obter os valores da freqüência de ocorrência segundo Mateucci, Colma (1982), utilizou-se a seguinte fórmula: F_0 = a. 100/A, em que:

F_0 = freqüência de ocorrência;

a= número de amostras em que o táxon analisado ocorreu;

A= número total de amostras.

Os resultados foram expressos como:

> 70% - Muito freqüente

≤ 70% e > 40 - Freqüente

≤ 40% e > 10% - Pouco freqüente

≤ 10% - Esporádica

Para obter os valores da diversidade específica, ou seja, o grau de complexidade da estrutura da comunidade, foi utilizada a seguinte fórmula, segundo Shannon (1948): $H' = \sum pi \cdot \log_2 pi$, onde:

H' = diversidade específica

Pi = ni/N, em que:

ni = número de células de cada espécie

N = número total de células

De acordo com o índice proposto por Shannon (1948), os valores foram enquadrados na seguinte classificação:

≥ 3,0 $bits.ind^{-1}$ representa uma alta diversidade;

<3,0 ≥ 2,0 $bits.ind^{-1}$ representa uma média diversidade;

<2,0 ≥ 1,0 $bits.ind^{-1}$ representa uma baixa diversidade;

<1,0 $bits.ind^{-1}$ representa uma diversidade muito baixa.

A distribuição do número de células por táxon, Equitabilidade, foi calculada com base em Pielou (1967), utilizando-se a seguinte fórmula: J' = H'/ $\log_2 S$, em que:

J' = equitabilidade

H' = diversidade específica

S = numero total de espécies de cada amostra

Adota-se para este índice valores entre 0 e 1, sendo que > 0,5 indicam boa distribuição dos indivíduos entre as espécies.

Com relação ao zooplâncton, os cálculos das análises multivariadas foram feitos utilizando-se apenas as matrizes de densidade ($org.m^{-3}$), que são os dados mais comumentes usados. O método de agrupamento (*Cluster analysis*), após medição da similaridade pelo coeficiente de correlação momento-produto de Pearson onde se aplicou a transformação linearizante Log(x+1) dos dados. Esta transformação, que consiste na homogeinização das variâncias, foi aplicada para diminuir a distorção dos resultados, sendo a mais eficaz no caso de dados planctônicos (IBANEZ, 1976). A classificação utilizada foi a aglomerativa hierárquica do "Peso proporcional" (*Weighted Pair Group Method* - WPGM). Este método consiste em dividir um conjunto de objetos (amostras) ou descritores (variáveis - táxons zooplanctônicos) em subconjuntos, de forma que cada objeto ou descritor pertença a um único subconjunto. As relações entre os constituintes de um subconjunto e entre os diversos subconjuntos são quantificadas, evidenciando associações significativas (LEGENDRE, LEGENDRE, 1998). O resultado da classificação é visualizado sob a forma de um dendrograma. Esta representação, em um espaço bi-dimensional, de relações multidimensionais geram certas distorções, cuja intensidade pode ser estimada comparando por correlação a matriz original com a matriz tirada do dendrograma, chamada de matriz dos valores cofenéticos. O coeficiente de correlação resultante é chamado de correlação cofenética e pode ser usado para medir a validade do agrupamento, cujo valor > 0,8 indica dados bem ajustados (ROHLF, FISHER, 1968). Após a construção dos dendrogramas, o nível do corte para definir os grupos foi selecionado na base da interpretabilidade ecológica da classificação (LEPS *et al.*, 1990). A escolha do "Peso proporcional" se deve ao fato, de permitir um aumento no contraste da classificação sem distorção desmesurada do dendrograma (coeficiente de correlação cofenética elevado).

A análise fatorial em componentes principais, que permite evidenciar e hierarquizar os fatores (eixos = componentes) responsáveis pela variância dos dados. Este método de ordenação em espaço, sintetiza as principais tendências de variação e sua representação gráfica em espaço multidimensional é projetada em um número reduzido de planos. A matriz formada com as fazendas foi submetida a uma padronização (*standardization*) por fileiras, para reduzir os efeitos das diferentes escalas. Em seguida, foi calculada a similaridade por correlação, e daí, computou-se os autovalores da matriz de dispersão (mede a variância associada a cada eixo principal), estando associado a cada um destes autovalores, autovetores, que correspondem aos eixos principais do espaço multidimensional. O primeiro eixo principal descreve a maior dimensão da elipsóide multidimensional, enquanto que os eixos principais seguintes passam por dimensões sucessivas, gradativamente menores (LEGENDRE, LEGENDRE, 1998).

Todos estes cálculos foram feitos utilizando o programa computacional NTSYS (*Numerical Taxonomy and Multivariate Analysis System*) da Metagraphics Software Corporation, California - USA.

4.3 Normalização

O texto foi normalizado tendo como base às recomendações da Associação Brasileira de Normas Técnicas – ABNT. Para a estruturação do texto foi utilizada a norma NBR 14724:2005. As citações de documentos ao longo do texto foram ordenadas de acordo com a norma NBR 10520:2002 e a padronização das referências bibliográficas baseando-se na norma NBR 6023:2002. Os artigos científicos foram normalizados de acordo com as exigências das revistas aos quais foram submetidos.

6 Artigos Científicos

ARTIGO 1

Plankton Community as Indicator of Water Quality in Tropical Shrimp Culture Ponds.

Submetido à **Marine Pollution Bulletin.**

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Plankton community as an indicator of water quality in tropical shrimp culture ponds

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Abstract

The plankton was examined as an indicator of water quality in 14 shrimp *Litopenaeus vannamei* farms in Brazil in 2005. The ponds were categorized by high stocking density (>30 PL m^{-2}) of phytoplankton, consisting of 51 species with concentrations ranging from 365,218 ± 416,615 cells mL^{-1} to 1,961,675 ± 3,160,172 cells mL^{-1}. Diatoms contributed to almost 70% of the species number and high densities resulted from Cyanophyta blooms, mainly *Pseudanabaena* cf *limnetica*. Forty zooplankton taxa were registered and were essentially composed of typical marine euryhaline species and suspension-feeders. Copepoda dominated (45%) the make-up, followed by Protozoa (18%), Rotifera (12%), and Mollusca (12%) larvae. Zooplankton varied from 972 ± 209 ind m^{-3} to 4235 ± 2877 ind m^{-3}. Enhanced nutrient input affected plankton density and composition. Diatom and copepoda dominance was replaced by cyanobacteria, protozoan, and rotifers as nutrient concentrations increased with the cultured period, indicating that plankton structure is affected by eutrophic conditions.

Keywords: Phytoplankton; Zooplankton; Aquaculture; Shrimp ponds; *Litopenaeus vannamei*; Brazil

1. Introduction

The expectation for aquaculture to increase its contribution to global food supplies and the sustained global demand for shrimp, which cannot be met by fisheries alone, provides an economic incentive for intensive shrimp farming (Burford et al., 2003). However, shrimp culture requires water, land, and other natural resources, which inevitably interact with the environment. The expansion of shrimp farming in many coastal regions is the leading cause of the loss of mangrove forests. Furthermore, other forms of coastal deterioration by shrimp farms (eutrophication, use of antibiotics, introduction of exotic species etc.) have lead to wide-spread criticism (Naylor et al., 1998; Alongi et al., 1999) and global efforts to develop sustainable shrimp production management practices (Samocha et al., 2004).

Mariculture is a recent development of the Brazilian agribusiness, and has increased by about 20% per year during the last decade, particularly along the semi-arid north eastern coast of Brazil, due to the good weather conditions and environmental setting (Lacerda et al., 2006).

Cultured shrimp has been the driving force behind the strong increase in shrimp trade during the late 1980s and early 1990s, making its value the most important seafood product traded internationally. In fact, over one quarter of the shrimp traded internationally comes from aquaculture

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(FAO, 1998). This rapid development has been accompanied by increasingly controversial debates over the environmental, social, and economic impacts of shrimp culture (Paez-Osuna et al., 1998, 1999; Primavera, 1998; Costanzo et al., 2004; Sampaio et al., 2005). There is considerable uncertainty about appropriate policy and management responses, especially as shrimp culture is perceived to generate substantial benefits in coastal regions and at the national level (Rocha et al., 2004).

The rapid expansion of shrimp farming in Brazil has focused attention on the need for effective management strategies. Such strategies are needed to enhance the positive contributions that shrimp farming and other forms of coastal aquaculture can make to economic growth and poverty alleviation in coastal areas, while controlling negative environmental and social impacts that may accompany poorly planned and regulated developments (Rocha et al., 2004).

The water quality associated with aquaculture developments is an important concern globally, as a variety of negative environmental impacts on the receiving environment have been documented (Landesman, 1994; Lacerda et al., 2006). Most importantly, it is the water quality that will influence optimal shrimp growth and yield. Classically, an investigation of water quality involves a combination of physical variables and biological indicators (Jones et al., 2001). The fact that intensive mariculture often involves the addition of various feeds, fertilizers, and chemicals to stabilize the earthen pond bottoms, the use of only classic physicochemical variables to accurately assess the water quality in and around these systems may be inadequate.

Additionally, there is still insufficient information on the use of the plankton communities as biological indicators of water quality associated with culture systems, especially in marine environments.

Phytoplankton and zooplankton make excellent indicators of environmental conditions and aquatic health within ponds because they are sensitive to changes in water quality. They respond to low dissolved oxygen levels, high nutrient levels, toxic contaminants, poor food quality or abundance, and predation. A good picture of the current conditions in the ponds can be derived by looking at plankton indicators, such as their biomass, abundance, and species diversity (Burford, 1997; Primavera, 1998).

Because it is desirable that ponds and other waters should support phytoplankton and zooplankton species for maintaining good water quality as well as providing a quality food source for the others consumers, it is important to elucidate the trends of species dominance and the probable factors controlling the community structure. Therefore, the objective of this study is to provide information on the usefulness of phytoplankton and zooplankton species as indicators of water quality in shrimp aquaculture.

2. Materials and methods

This research was based in 108 phytoplankton and 108 zooplankton samples collected during three sessions (C1, C2 and C3) from October 10th to November 19th 2003 from 14 farms that intensively cultivate the marine shrimp *Litopenaeus vannamei*. C1 was carried out from 19th to 25th October, C2 from 1st to 7th November, and C3 from 14th to 17th November. On each farm, two ponds (P1 and P2) and the water intake point (IP) were monitored. The farms are located in Ceará, Piauí and Rio Grande do Norte states – Brazil (Table 1, Fig. 1) and produce shrimp by intensive culture (30–80 shrimp m^{-2}), in ponds, typically 1 ha each in size with earthen floors, feeding exclusively with a balanced commercial ration. The mean survival rate varied from 42.53 to 55.12%, the days of cultivation from 132 to 159 days, and the final weight from 10.66 to 12.54 g.

Water samples for phytoplankton were collected with a 100 mL plastic bottle, and samples were preserved with 1% Lugol's iodine solution. Quali-quantitative analyses were carried out in the laboratory using the Ütermöl method under an inverted microscope. The phytoplankton composition was based on the identification of the specific and infra-specific taxa.

Zooplankton sampling at each station was collected with a standard plankton net of 1 m length, 30 cm mouth diameter, and mesh size of 50 μm fitted with a flowmeter (Hydrobios, Kiel). Three minutes of horizontal sub-surface hauls were made at each pond. Samples were preserved in a

Table 1
Shrimp culture farms in Northeastern Brazil

FARMS (City)	Latitude	Longitude	Survival (%) min–max[b]	Days of cultivation min–max	Final Weight (g) min–max
Ceará State					
Promares, Aquafort and Samarisco (Camocim)	2°54'S	40°50'W	40.46–70.11	102–158	9.73–14.28
Papagaio and AS Marina (Acaraú)	2°50'S	40°07'W	43.62–52.90	120–172	10.23–11.11
Compescal, Cina and Vip Camarões (Aracati)	4°33'S	37°46'W	32.58–52.78	116–162	10.28–11.23
Piauí State					
Camapi, Secom and Camarões do Brasil (Cajueiro da Praia)	2°55'S	41°20'W	52.51–68.10	128–160	10.24–11.04
Rio Grande do Norte State					
Potiporã[a], MRG[a] and Aquatica[a] (Pendências)	06°16'S	36°29'W	37.57–46.27	142–174	11.03–11.21

[a] Samples collected during the 2nd and 3rd campaigns.
[b] Min–max = Minimum and maximum Data information: http://www.abccam.com.br/.

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Fig. 1. Studied area in Northeastern Brazil showing the municipalities where the farms are located.

4% buffered formalin/seawater solution. Zooplankton species were identified to the lowest taxonomic unit possible, and taxon abundance (per cubic meter) was counted under a microscope (1 mL sub sample). These samples were taken with a Stempel-pipette (250 mL) from the entire sample.

The Shannon index (H') was applied for the estimation of phytoplankton and zooplankton community diversity based on $\log_2$ (Shannon, 1948). Evenness was calculated according to Pielou (1967).

To verify potential correlations between farms, Spearman rank correlation analysis (Zar, 1990) was performed at $\alpha = 0.05$. One-way Kruskall–Wallis ANOVA (Zar, 1990) was used to test for significant ($\alpha = 0.05$) effects of the factors "station", "campaign", and "farm" on the phyto- and zooplankton data from all farms. No effect of the factor "State" was tested as Ceará State had eight of the 14 farms. These analyses were performed with STATISTICA 5.1 (StatSoft Inc.).

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3. Results and discussion

3.1. Phytoplankton

The exclusive use of physicochemical indicators to assess the water quality of intensive mariculture system is insufficient, particularly if there is an investigation into the extent of the influence of the farm wastewater on the immediate environs. This observation concurs with previous studies concluding that the use of traditional water quality indices to determine the effect of aquaculture effluent on the receiving environment is mainly limited to areas near to the discharge point (Samocha and Lawrence, 1995).

The use of phytoplankton biomass as an indicator for this type of system is sufficient, but it has specific limitations. Firstly, the total chlorophyll *a* values may be underestimated in areas having high macroalgal populations. The absorption of nutrients by the macroalgae may result in an underestimated biomass value and, consequently, an inaccurate characterization of the water quality. The size fractions of the phytoplankton are important on a microscopic level in the determination of water quality. However, the presence of colonial phytoplankton species may overestimate the contribution of a size class to the total biomass at that site. Thus, it is important to know the species composition, as phytoplankton undergoes a continual succession of dominant species due to dynamic changes of growth factors like light, temperature, and nutrient concentrations in an aquatic environment (Goldman and Mann, 1980; Yusoff and McNabb, 1997; Yusoff et al., 2002).

In the studied shrimp ponds, a total of 51 species were identified, with diatoms contributing to 69% of the species list followed by Pyrrophyta (8%), Cyanophyta (12%), Euglenophyta (4%), and Chlorophyta (6%). This confirms the high diversity of diatoms in estuarine waters. The less representative algae were Euglenoficeans and Criptoficeans that were represented by only one species each. Phytoplankton does not only affect water quality, but also the other organisms along the food chain. Centric diatoms have been classified as the most desirable phytoplankton in coastal waters (Ryther and Officer, 1981) because they are important as food items for higher consumers (Boyd, 1990). However, some marine diatoms negatively affect the reproduction of dominant zooplankton grazers such as copepods, thus compromising the transfer of energy through marine food chains. For example, some centric species (*Chaetoceros armatus* and *C. concavicornis*) can form noxious blooms that have been implicated in fish kills for at least 30 years, the causative mechanism being unknown (Horner et al., 1991). Some diatoms are producers of toxins or grazing deterrents (D'Ippolito et al., 2003; Romano et al., 2003; Fontana et al., 2007).

In areas where temperature is high and light is abundant (like in Northeastern Brazil), nutrient concentrations and ratios become important environmental factors influencing the dominance of various taxonomic groups (Smith, 1983; Yusoff and McNabb, 1997). In general, algae from diverse groups have remarkably similar physiological and compositional response to nutrient limitation. Thus, such responses are useful indicators of nutrient status (Healy, 1973).

The most frequent phytoplankton species in the studied ponds were *Pseudoanabaena limnetica* cf., *Scrippsiella trochoidea*, *Gymnodinium* sp., *Cyclotella meneghiniana*, and *Chlorella* sp. Smith (1983) reported that nutrient-loading ratios can exert a strong selective effect on natural communities of phytoplankton. In shallow ecosystems like ponds, high availability of phosphorus and nitrogen in interstitial water can be an additional source of nutrients for phytoplankton blooms. Also, approximately 80% of the nitrogen added to ponds as shrimp feed is not retained in shrimp biomass, instead acting as a phytoplankton fuel (Sanders et al., 1987).

The dominance of the above phytoplankton species in most studied farms led to very low phytoplankton species diversity, with an average value on all farms of 0.76 ± 0.25 bits cell^{-1}, varying from 0.5 to 1.1 bits cell^{-1} (Fig. 2). The highly unbalanced system favored irregular blooms of some species, showing that the ponds present low species number and low evenness. According to Paerl (1988), blooms exist as massive accumulations of a single or less often two coexisting species with densities of 10^4–10^6 cells mL^{-1}, and the nuisance species account for as much as 95–99% of the resident biomass. Smith (1985) suggested that highly diverse algal communities are less likely to collapse than blooms dominated by one species.

Phytoplankton density varied from 365,218 cells mL^{-1} (Farm Cina) to 1,961,675 cells mL^{-1} (Farm Camarões do Brasil) (Fig. 3). High densities resulted from some species blooms in most studied ponds. Cyanophyta were in general responsible for these blooms, especially *Pseudanabaena* cf *limnetica* that attained values over 600,000 cells mL^{-1}, as in the farms Papagaio (pond 2), Compescal (pond 2), and Vip Camarões (pond 2), which showed stressed conditions. Other farms displaying this species with densities over 200,000 cells mL^{-1} (A. S. Marine, pond 1; Riograndense, pond 1 and 2; Aquafort, pond 2; Samarisco, pond 2) need to be constantly monitored.

Nutrient levels of the water and interstitial water of the sediments has usually been used to characterize the water trophic state. We suggest that phytoplankton composition and density could also be used as a complementary indicator of water trophy degree.

Pseudanabaena cf. *limnetica* presented high densities in some farms' intake water channel, where the densities were over 100 cells mL^{-1}. Papagaio, Vip Camarões and Rio Grandense farms were in this condition.

Another algae group with high densities was Chlorophyta, which presented very low species diversity. However, blooms of *Chlorella* sp. sometimes dominated the ponds. Blooms were registered in the farms Aquafort (pond 2), A. S. Marine (ponds 1 and 2), and Camapi (pond 1), where this species attained 1,000,000 cells mL^{-1}. Others farms must be monitored, as high densities were also registered

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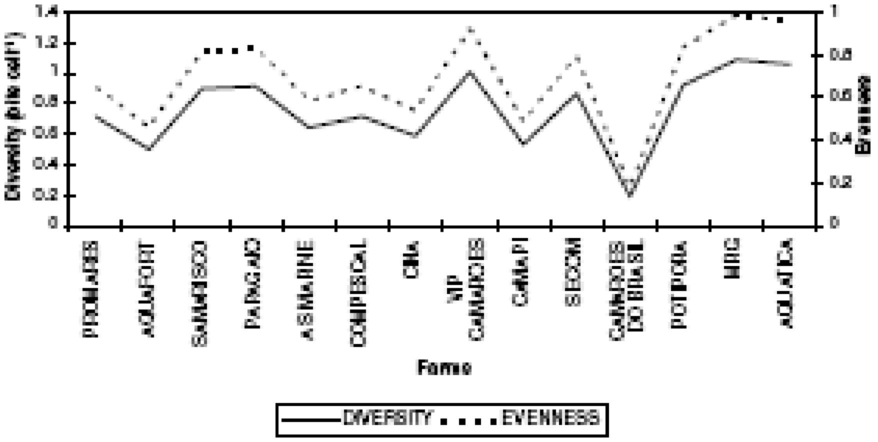

Fig. 2. Species diversity and evenness of the main phytoplankton groups in the shrimp farm ponds in Northeastern Brazil.

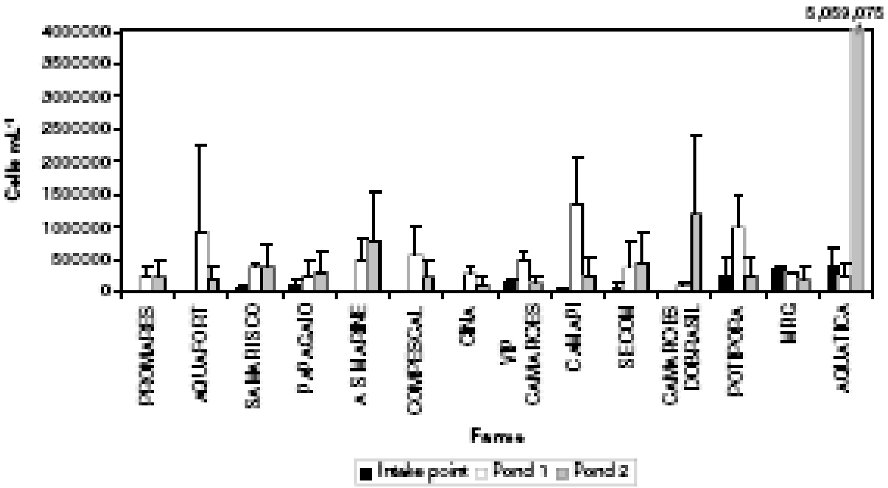

Fig. 3. Total phytoplankton average density and standard deviation in the shrimp farm ponds in Northeastern Brazil.

(over 200,000 cells mL^{-1}) in the farms Promares (pond 1), Samarisco (pond 1), Compescal (pond 1), and Vip Camarões (pond 1).

Studies carried out on phytoplankton on shrimp farms in Bangladesh by Islam et al. (2004) identified phytoplankton only to genera. Bacillariophyceae was the largest group by quality, being represented by up to 13 genera, while Pyrrophyceae was the smallest group, represented by only two genera. Bacillariophyceae numbers dominated two ponds, and Cyanophyceae dominated the other ponds. Phytoplankton density attained 211 cells mL^{-1}. The phytoplankton groups in the present study were almost the same as the assemblage found by Tookwinas and Songsangjinda (1999), who reported 79 genera in ponds of the shrimp farming system in Thailand, with concentrations ranging from 1822 to 72,527 cells mL^{-1}.

In shrimp ponds from Mexico, Rodriguez and Paez-Osuna (2003) listed 48 genera of phytoplankton that commonly occur in coastal areas. They also reported Bacillariophyceae, Cyanophyceae, Chlorophyceae, and Euglenophyceae as the dominant groups in coastal waters and in the shrimp farming systems. Among the most common pond types (intensive and semi-intensive), *Synechocystis diplococcus* (cyanobacteria) was the dominant species (>88.9%), followed by

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Peridinium trochoideum (*Scrippsiella trochoidea*), and eventually by *Prorocentrum minimum* and *Gymnodinium* spp. (dinoflagellates). The numerous occurrences of large blooms of dinoflagellates and other functional groups such as cyanobacteria, diatoms, chlorophytes, and flagellates mean economic losses for the farm industry on account of shrimp mortality or growth diminution due to poisoning, anoxic, or mucus production effects.

In the pristine marine tropical waters in Brazil, diatoms normally comprise more than 80% of the total phytoplankton (Eskinazi-Leça et al., 2000). As in other coastal regions of the world, with the onset of eutrophication, diatom population decrease and other groups of algae, such as dinoflagellates and cyanobacteria, persist (Sanders et al., 1987; Yusoff et al., 2002). This could be caused by silica depletion, as domestic waste waters are relatively poor in silica, leading to elimination of diatoms from the phytoplankton communities (Ryther and Officer, 1981).

Phytoplankton blooms involving excessive algal growth are common occurrences in aquaculture ponds, which often lead to die-offs, decrease of water transparency, absence of oxygen in the bottom layer, and accumulation of toxic compounds such as ammonia, nitrite, and hydrogen sulphide (Paerl and Tucker, 1995). Due to the rapid onset of nutrient limitation (mainly nitrogen) or infestation by microorganisms (saprophytic fungi, bacteria, or protozoans), surface blooms are rapidly transformed into undesirable decomposing mats (Paerl, 1997).

In general, this study showed that in marine shrimp culture ponds, diatom dominance was potentially replaced by cyanobacteria as nutrient concentrations increased and silica was depleted with the culture period. However, this dominance could also be more closely associated with low aquatic luminosity than nutrient enhancement (Scheffer et al., 1997). Data obtained from some lakes associated with mathematical models indicate that cyanobacteria dominance is an alternative stable-state of a phytoplankton community in shallow aquatic systems. This is because cyanobacterians are more adapted to low water transparence, and they promote the water turbidity, favoring their own competitive advantages (Scheffer et al., 1997). Moreover, the long water retention time and abiogenic turbidity increase the probability of cyanobacteria dominance in shallow, tropical aquatic systems (Scheffer et al., 1997). Therefore, the high temperature and turbidity of the water and the long water retention time in shrimp ponds (>100 days) must raise the probability of cyanobacteria blooms.

The tendency of low species diversity is indicative of an unbalanced system with decreasing water quality and cultured species. Better conditions were found in the intake channels. The identification of phytoplankton composition in shrimp ponds is very important in terms of system management. For that reason, the management of water quality as well as the cultured organisms in shrimp farms is a complex task, which can benefit from a previous knowledge of taxonomic structure and quantitative patterns of phytoplankton assemblages.

3.2. Zooplankton

Zooplankton indices are also very useful water quality indicators for the shrimp culture farms. They displayed fairly distinct patterns in the species composition and abundance as the water quality changed spatially. This may be attributed to the fact that the zooplankton community itself responds directly or indirectly to changes in the physicochemical variables and the availability of phytoplankton food (Raymont, 1980), and is therefore less affected by manipulation via farm management processes. There have been numerous studies investigating the general zooplankton response to various sources of stress, and subsequently, their use as a biological indicator has been well documented (Webber and Webber, 1998). Zooplankton assemblages comprise a significant component of the natural biota of shrimp aquaculture ponds and present rapid temporal changes in structure (Coman et al., 2003; Preston et al., 2003).

The zooplankton was essentially composed of typical marine euryhaline species, which were distributed in 40 taxa. The following Phyla were present: Sarcomastigophora, Cnidaria, Nematoda, Rotifera, Mollusca, Annelida, Crustacea, Bryozoa, and Chordata. The dominant taxa were Copepoda (16 species and made up 44% of relative abundance), mainly as the juvenile form (nauplii and copepodits), followed by Protozoa (18%), and Rotatoria (6 species with 12% of total relative abundance). The meroplankton was represented by Gastropoda and Bivalvia larvae (12%), Polychaeta larvae with 7% of relative abundance (dominated by small chaetosphaera spionids), nauplii of Cirripedia, and few Brachyura zoeae stage I, with a large distribution in the Northeastern Brazil region sometimes dominating the community.

Among Copepoda, predominately, the Brazilian euryhaline-estuarine indicators were formed by the young stage of *Parvocalanus crassirostris*, *Acartia lilljeborgi*, *Oithona oswaldocruzi*, *Oithona hebes*, and *Euterpina acutifrons* (Björnberg, 1981; Neumann-Leitão et al., 1999).

The Protozoa, which outranked the acetate ciliata and tintinnina *Tintinnopsis* spp. and *Favella ehrenbergi* as being characteristic of the eutrophic systems, were indicators of unbalanced conditions. Tintinnids constitute an important component of the planktonic microprotozoan community in most marine environments (Pierce and Turner, 1993; Tillmann, 2004), and can occasionally be important in estuarine waters (Urrutxurtu, 2004). High abundance, fast reproduction rates, and short generation times, as well as their high capacity to use a large spectrum of food resources enhance the importance of tintinnids as a key trophic link between the microbial and the metazoan compartments (Capriulo and Carpenter, 1983; Capriulo et al., 2002; Urrutxurtu, 2004). In the recent past, researchers drew attention to the presence of large numbers of ciliates in intensive shrimp production systems, at least during part of the production cycle (Bratvold et al., 1999). However, their occurrence and role in the shrimp production systems

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have seldom been investigated. Decamp et al. (2007), studying shrimp culture ponds, found that free-swimming ciliates were dominant in the early stages of production and showed that ciliates could reach very high concentrations, over 6000 cells mL^{-1}, within zero-water exchange shrimp production systems. However, none were identified.

Copepods, other crustaceans, larvae of polychaetes, larvae of insects, mollusks, ostracods, and rotifers have been considered the most important sources of food for shrimp (Rubright et al., 1981). The assemblages found in the studied ponds have a variety of roles within the pond ecosystem. Grazing zooplankton influences the dynamics of pond phytoplankton (Coman et al., 2003). Predation on zooplankton by shrimp (Martinez-Cordova et al., 1998) may transfer a significant proportion of the nutrients from natural biota to the shrimp tissue (Anderson et al., 1987), feces, and water. This, together with the nutrient input through shrimp rations, leads to the typically nutrient rich environment in shrimp ponds.

Rotifers *Brachionus plicatilis* were abundant in the aquaculture ponds. Rotifers are a valuable live food for larval fish and crustacean culture and have also been used as indicators of trophy (Saksena, 1987). Several characteristics of rotifers, including their nutritional quality, body size, and relatively slow motility, have contributed to their usefulness as good prey for active larvae (Snell and Carrillo, 1984). The rotifer *Brachionus plicatilis* has been most widely used as an essential food source in raising marine fish, shrimp, and crab larvae due to its tolerance to the marine environment (Lubzens, 1987). The rotifer *B. plicatilis* is a euryhaline species, and in nature, density peaks of these species are associated with high eutrophication near villages and/or processing plants of aquatic and/or poultry products (Fenggi, 1996). *B. plicatilis* and others rotifer species dominated the estuarine region of the Ipojuca river (Northeastern Brazil), which receives high sewage loads from many cities and industries (Neumann-Leitão et al., 1992). Thus, the presence of these rotifers in high densities is indicative of the shrimp ponds nutrient enrichment and quality decrease.

Many stages of Nematoda, found at Cina and Papagaio farms, belonged to *Ancylostoma duodenale*. According to Rey (2002), the larvae develop in the aquatic environment during the rainy season between temperatures between 23 and 30 °C, and the adults develop well in humid soil, rich in organic residuals.

In general, species diversity was low, following the same pattern as the phytoplankton. The lowest diversity index was found in Aquafort farm (1.26 bits ind^{-1}) and the highest at Promarés farm (1.75 bits ind^{-1}) (Fig. 4), due to few species, a common fact in estuarine waters (Tundisi, 1970) and in eutrophication conditions like in the ponds. Minimum evenness was registered at the Aquafort farm (0.44), caused by the dominance of few species (mainly sessile ciliata and Copepoda nauplii). The maximum was 0.6 (Fig. 4) at Vip Camarões farm, where the ecosystem presented better water quality, although still a somewhat poor condition.

Zooplankton total density by farm was high, with a minimum of 2915 ind m^{-3} (Vip camarões farm) and a maximum of 12,706 ind m^{-3} (Compescal farm). The average zooplankton abundance by site varied from 221.77 ± 152.12 ind m^{-3} (Cina farm, Pond 1) to 2513.35 ± 1603.56 ind m^{-3} (Compescal farm, Pond 1) (Fig. 5), with an average of all farms and sites of 2255 ± 975 ind m^{-3}.

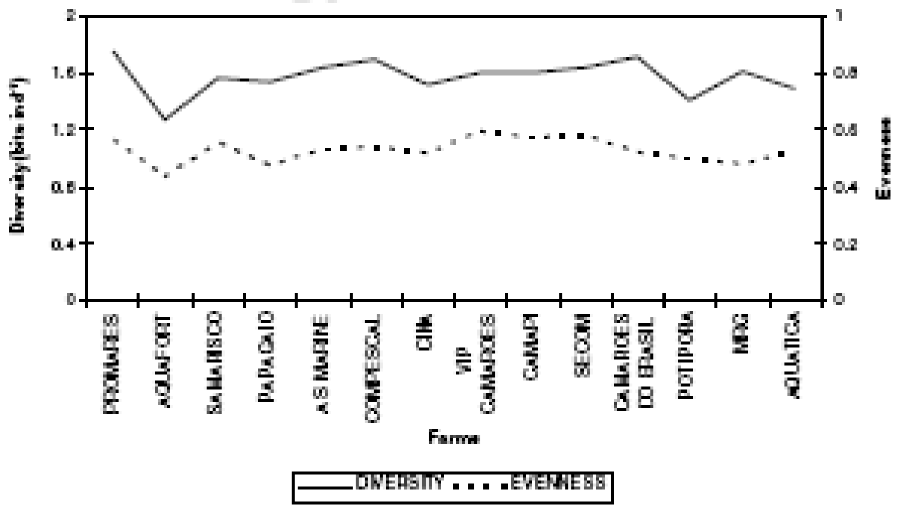

Fig. 4. Species diversity and evenness of the main zooplankton groups in the shrimp farm ponds in Northeastern Brazil.

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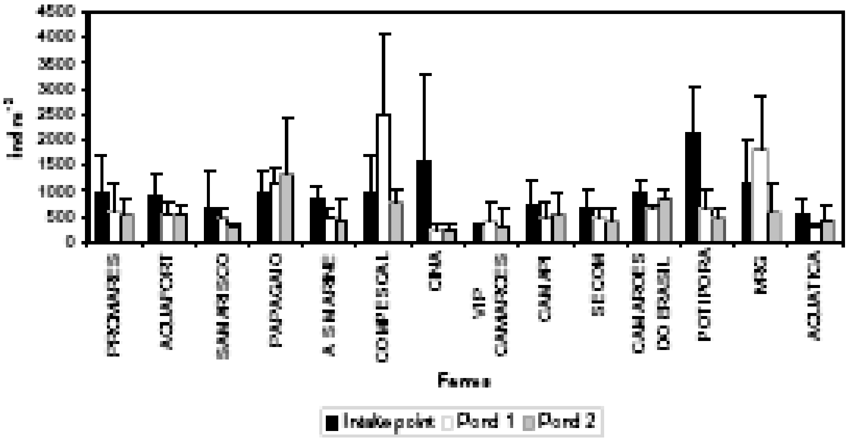

Fig. 5. Total zooplankton average density and standard deviation in the shrimp farm ponds in Northeastern Brazil.

In general, the intake areas presented better conditions than most ponds, which were often dominated by organic pollution indicators (aloricate ciliates, rotifers, polychaeta larvae, nematode, among others). Even presenting strong organic decomposition, there were copepods nauplii and Bivalve larvae in high densities, showing the great importance of the marine flux in renewing the environment and improvement of environmental health, as it was stated for a highly impacted estuarine area from Northeastern Brazil (Neumann-Leitão and Matsumura-Tundisi, 1998).

It can be concluded that the high amount of aloricate ciliates, mainly in the ponds of the Secom and Aquafort farms, indicated a poor water quality. In general, colonization by ciliates occurs concurrently with high levels of organic matter. The dominance of these species in the ponds can favor the bacterioplankton control and add additional food to the ponds. However, in high quantities as presently found in the ponds, indicating an enriched organic matter environment, the effluent of theses ponds can negatively impact the water of the receptor area. In the Cina farm, a Mysis stage with ectoparasites protozoan like *Vorticella* spp. was registered. These parasites negatively affect the molts and development of the infected organisms, a fact that was observed in this farm and also in the Papagaio farm, where a parasitic nematode was registered.

Studies of zooplankton in shrimp ponds have shown that these are complex assemblages with rapid temporal changes in structure (Coman et al., 2003). The main factors influencing these changes are variations in source of food, predation, and the influences of variations in physical and chemical water quality parameters. The results here suggest that nutrient input provided by shrimp food decomposition affected both the density and the relative species composition of the plankton community. Therefore, plankton assemblages could be an excellent bioindicator of water quality of shrimp ponds. These results can be important in our understanding of the effects of eutrophication in coastal plankton structure and to marine aquatic food web.

3.3. Statistical analysis

The factors "station", "campaign", and "farm" on the phyto- and zooplankton data from all farms showed that among the three factors considered, only the factor "station" showed significant differences ($p < 0.05$). These differences were registered between the intake point and the two studied ponds of each farm. Spearman correlation analysis presented similarities between the Promares and Secom farms and among the Aquafort, Cina, Camapi and Potipora farms. Similar results were found for the differences in key abiotic parameters, (e.g. nutrient concentrations, oxygen demand, and total suspended solids) between intake channels and effluents in shrimp ponds in Texas and Taiwan (Samocha et al., 2004), showing that the alteration of water quality through shrimp farming is a wide-spread problem.

Acknowledgments

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ARTIGO 2

Cyanobacteria as environmental quality indicator in shrimp farming in Northeastern Brazil.

A ser submetido à **Harmful Algae.**

Title:

Cyanobacteria as environmental quality indicator in shrimp farming in Northeastern Brazil

Authors:

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ABSTRACT

We examined diversity and abundance of cyanobacteria as environmental quality indicator in 14 shrimp farms culturing Litopenaeus vannamei Boone, 1931 in Northeastern Brazil, in 2003. These farms are located in Piaui, Ceará and Rio Grande do Norte states. In our study we identified altogether 12 infrageneric cyanobacteria taxa. Higher floristic richness (11 taxa) was found in Ceará State. Piauí presented four taxa and Rio Grande do Norte presented 3 taxa. Cyanobacteria total density varied from $2.5\ 10^5$ cell mL^{-1} to $25\ 10^6$ cell mL^{-1}. In the ponds the density was higher than in the captations points and increased from 27 cell.mL^{-1} to 600,000 cell.mL^{-1}. High densities of Cyanobacteria in the farms were caused by Pseudanabaena cf. limnetica. The low species number and the dominance of only one specie (*P.* cf. *limnetica*) in all ponds indicated an unbalanced system, showing that Cyanobacteria could be an important water quality indicator.

Key words: cyanobacteria; blooms; shrimp culture; tropical.

1. Introduction

The increasing demand for shrimp worldwide is a strong economic incentive for intensive shrimp farming in the tropics. However, the negative environmental impacts in many coastal regions have prompted widespread criticism (Naylor et al., 1998) and global efforts to develop more sustainable farming techniques (Preston et al., 2001). A major problem with shrimp farms is the discharge of pond waters and nearly 80% of nitrogen added to ponds as shrimp feed is not retained as shrimp biomass (Briggs and Funge, 1994; Jackson et al., 2003). Remaining nitrogen stimulate plankton and microbial production within ponds, often resulting in negative effects on pond water and sediment quality such as anoxia, nutrient toxicity, and blooms of undesirable algal species (Moriarty, 1997; Burford and Glibert, 1999).

Cyanobacteria often are the cause of extensive and persistent blooms in aquaculture ponds. According to Paerl and Tucker (1995) bloom-forming cyanobacteria are undesirable because: 1) they are a relatively poor base for aquatic food chains; 2) they are poor oxygenators of the water and have undesirable growth habits; 3) some species produce odorous metabolites that impart undesirable flavors to the cultured animal; and 4) some harmful species may produce compounds that are toxic to aquatic animals.

Among the toxins (hepatotoxic microcystins, nodularins, and cylindrospermopsin) the microcystins and nodularins are potent toxins, which are also tumor promoters and may accumulate into aquatic organisms and be transferred to higher trophic levels, and eventually affect vector animals and consumers (Scott Yoo et al., 1992; Duy et al., 2000; Pérez-Linares et al., 2003; Kankaanpää et al., 2005).

Shrimp farming is a rapidly growing industry in Brazil and because information regarding effects of cyanobacteria at shrimp farms is lacking, we examined diversity and abundance of cyanobacteria as environmental quality indicator in 14 shrimp farms culturing L. vannamei in Northeastern Brazil.

2. Material and Methods

This research was based in 108 phytoplankton samples collected during three campaigns from October 10th to November 19th 2003 in 14 farms that cultivate the marine shrimp L. vannamei. Campaign 1 was carried out from 19 to 25/October; Campaign 2 from 01 to 07/November; Campaign 3 from 14 to 17/November. In each farm, two ponds and the water intake point were monitored.

The studied farms are located in Ceará, Piauí and Rio Grande do Norte States - Brazil (Tab. 1 and Fig. 1). The farms produce shrimp by intensive culture (30 to 120 shrimps.m^{-2}), feeding exclusively with balanced ration.

Water samples for cyanobacterial analysis were collected with 100 mL plastic bottles and samples preserved with 1% Lugol's iodine solution. In laboratory, quali-quantitative analyses were carried out using the Utermöhl (1958) method under an inverted microscope. Cyanobacteria were counted and identified at 400 X to the lowest possible taxonomic level using appropriate keys. The composition was based on the identification of the specific and infra-specific taxa (Desikachary, 1959; Anagnostidis and Komárek, 1988; 1989; 1998; 2005). A minimum of 100 microscope fields, or 100 individuals of the most dominant taxa were counted, whichever came first. This method was considered quantitative for the larger (> 5 – 10 µm) taxa.

3. Results

In this present study were identified altogether 12 infrageneric cyanobacteria taxa (Tab. 2). The highest richness was found in Samarisco farm (CE), where six taxa were registered. Higher floristic richness (11 taxa) was found to Ceará State. Piauí presented four taxa and Rio Grande do Norte presented three taxa.

Cyanobacteria total density varied from 83,868 cells mL^{-1} (Farm Camapi) to 835,450 cells mL^{-1} (Farm Vip Camarões) (Fig. 2). In the ponds minimum density was 77,385 cells mL^{-1} (Farm Camapi) and maximum 2,257,692 cells mL^{-1} (Farm Camarões do Brasil) (Fig. 3). Density varied a lot in the farms. During the first campaign the density increased from 21,376 cells mL^{-1} (Farm Camapi) to 1,219,048 cells mL^{-1} (Farm Papagaio). During the second campaign the Compescal farm presented a density of 1,404,104 cells mL^{-1} and Camarões do Brasil farm 41,542 cells mL^{-1}. In the campaign from /November 14 to 17 the density varied from 101,465 cells mL^{-1} (Farm Aquatica) to 2,098,331 cells mL^{-1} (Farm Camarões do Brasil) (Fig. 4).

The order Chroococcales, with coccoid morphology were present only in Ceará state. Chroococcus sp. occurred in pond 2 (Cina farm) with 155,556 cells mL^{-1} and Merismopedia sp. at pond 1 (Aquafort farm) with 2 cells mL^{-1}. Both are colonies occurring preferentially in limnetic environment.

The order Oscillatoriales was found in all analyzed samples. Geitlerinema amphibium occurred during campaign 2 in pond 2 (Samarisco farm) with 8 cells mL^{-1} and in intake point of Camapi farm, during Campaign 3 with 2 cells mL^{-1}. Oscillatoria subbrevis presented 2 cells mL^{-1} in pond 1 of Aquaforte and Promares farms, during the first and second campaign, respectively. It also occurred in Camarões do Brasil farm, during campaing 2 in the intake point and in pond 2, with 2 cells mL^{-1}.

Oscillatoria sp. was present only with 6 cells mL^{-1} at the intake point of Camarões do Brasil farm during campaign 3.

Most taxa (e.g. Geitlerinema and Oscillatoria) presented a restrict occurrence, however, Pseudoanabaena cf. limnetica was present in all farms and absent only in few samples.

Pseudoanabaena sp. was registered in Promares farm, during campaign 2 in intake pond with 6 cells mL^{-1}) and in campaign 3 in ponds 1 and 2, with 2 and 4 cells mL^{-1}, respectively.

High densities of cyanobacteria in the farms were caused by Pseudanabaena cf. limnetica, a filamentous organism (until 12 µm length) which attained more than 2,000,000 cells mL^{-1}, in Camarões do Brasil farm, Compescal farm and Vip Camarões farm, showing a stressed condition. Other farms presented this species in densities over 500,000 cells mL^{-1} (A. S. Marine, MGR, Aquafort and Samarisco) (Fig. 5).

In the order Nostocales, where occur individuals with differentiated cells (heterocites and acinetes), species of the genus Anabaena (A. constricta and A. spiroides) occurred in Ceará and Rio Grande do Norte State. They were registered with low densities in campaign 2 and 3. Cylindrospermopsis raciborskii occurred in pond 2 of Samarisco farm, during Campaign 2, with 17 cells mL^{-1}. In the same sample occurred the species Raphidiopsis indica (2 cells mL^{-1}). The best represented genera was Anabaenopsis, which occurred in the intake points of Cina and Vip Camarões farms with 1,400 cells mL^{-1} at campaign 1 and 9,524 cells mL^{-1} in campaign 2, respectively.

Discussion

Depending on several factors in coastal lagoons, there are dominant groups: diatoms, dinoflagellates, cyanobacteria, chlorophytes, phytoflagellates, silicoflagellates and euglenophytes. Among the most important variables for the dominance of a given group, there are sources of water supply (a river or the sea), salinity and dynamic aspects of a lagoonal system (e.g. tidal regime, stratification, water exchange) (Alonso-Rodríguez and Páez-Osuna, 2003).

However, development of nuisance cyanobacterial blooms is favored when occurs a proper combination of multiple interacting physical, chemical, and biotic factors (Paerl, 1988), as under conditions of high nutrient loading rates (particularly if the availability of nitrogen is limited relative to phosphorus), low rates of vertical mixing, and warm water temperatures as in Northeastern Brazil.

Cyanobacteria are always found in close association with a diverse array of microorganisms, including eubacteria, fungi, and protozoans. These associations, which in the past have often been viewed as antagonistic, are increasingly seen as mutualistic and may function in a positive manner during bloom development (Paerl and Tuker, 1995).

Generally, blooms exist as massive accumulations (10^4 to > 10^6 cells mL^{-1}) of a single or, less often, two coexisting nuisance species-the nuisance species accounting for as much as 95 - 99% of the resident phytoplankton biomass. Both cyanobacteria and dinoflagellate bloom taxa are highly motile; and a high degree of motility allows for rapid vertical movement along light, temperature, and nutrient gradients; this characteristic is of obvious advantage under periodic resource-limited conditions. In the studied ponds cyanobacteria density varied from 251,605 cells mL^{-1} (Farm Camapi) to

2,506,349 cells mL^{-1} (Farm Vip Camarões). In Auburn (Alabama) phytoplankton density in semi-intensive culture ponds was 10^6 cells.mL^{-1} (Fast and Lannan, 1992), and in extensive culture ponds the density was 86 10^5 cells.mL^{-1} (Jonhnston *et al*., 2002) and in fertilized ponds density was 2 10^{10} cells.mL^{-1} (Boyd, 1990). Thus, the cyanobacteria densities found in our studies are similar to other farms culturing shrimps all over the world.

In ponds, the relation between phytoplankton quality and the culture development has been demonstrated by Dall et al. (1990). Blooms produce hipoxia or anoxia resulting in shrimp mortality (Alonso-Rodríguez and Páez-Osuna, 2003).

Cortés-Altamirano et al. (1995) mentioned that in two shrimp culture farms in Southeast Sinaloa, Mexico, in semi-intensive and intensive systems the cyanobacteria dominated with 3,5 10^9 cells mL^{-1}, in both systems. Cortés-Altamirano (1994) and Cortés-Altamirano and Licea-Durán (1999) registered the growth decrease in semi-intensive ponds caused by blooms of the cyanobacteria Synechocystis diplococcus (3,4 10^6 cells mL^{-1}) and Schizothrix calcicola (140 10^6 cells mL^{-1}). The density found in the present research shows that results are similar to those of these regions.

In most shrimp farms from the Golf of California coastal waters are used to supply water to the ponds and in general the dominant groups are diatoms and dinoflagellates (Licea et al., 1995; Moreno et al., 1996). Bufford (1997) showed that the species composition in the ponds were different from the adjacent natural waters with an increase of cyanobacteria, and this was related to changes in nitrogen-to-phosphorus ratios and ammonia concentrations. Thus, the patterns presented to Northeastern Brazil farms are similar to those from other countries.

Cyanobacteria also typically dominate phytoplankton communities in catfish aquaculture ponds in the southeastern USA during the summer and early autumn months (Tucker and Lloyd, 1984). These ponds receive a large input of catfish feed and this high nutrient loading promotes dense cyanobacteria blooms and increases water turbidity. In Mexico the high abundance of cyanobacteria in intensive and semi-intensive aquaculture was related to high tax of N/P (10.3) (Cortés-Altamirano et al., 1994; Páez-Osuna et al.,1997). The predominance of cyanobacteria can be attributed to their ability to regulate cell buoyancy due to formation, collapse, and reformation of intracellular gas vacuoles which provides These organisms with a competitive advantage over other types of phytoplankton for light and nutrients (Paerl and Tucker, 1995; Hargreaves, 2003).

Yusoff et al. (1998) found cyanobacteria with 89% of the total phytoplankton community in euthrophic ponds. Once established, the cyanobacteria cause an increase in pH due organic carbon reduction which favors their growth inhibiting other desirable species development (Yusoff et al., 2002). A better understanding about phytoplankton and physic-chemic relationships are necessary to stabilize phytoplankton blooms and to promote optimum conditions to shrimp productivity (Bufford, 1997). This suggests an improvement in management practices in Brazil.

Alonso-Rodríguez and Páez-Osuna (2003) reported that an excessive nutrient supply, as occurring in coastal areas, can cause an enrichment that can promote alage blooms a high primary productivity and macrophyta growth. Aditionally, nutrients excess can alter the phytoplankton composition, changing the dominant species, and these changes imply the substitution of big species by small. With the euthrophication diatoms decrease and other species as dinoflagellates and bluegreens dominate. In the studied farms the occurrence of 12 cianobacteria taxa can be an indicative of pond eutrophication.

In this present study P. cf. limnetica was the dominant species. According to Komárek and Anagnostidis (2005) P. limnetica (=Oscillatoria limnetica) is limnetic, benthonic occurring in bottom mud of ponds, lakes, artificial dams, being tychoplanktonic or planktonic, also in polluted waters; probably has a worldwide distribution in tropical and temperate zones. Nixdorf et al. (2003) mentioned that P. limnetica is typical in turbid mixed layers with highly light deficient conditions.

Other Oscillatoriales species registered in the present studies as G. amphibium and O. subbrevis are cosmopolitans occurring in freshwater and brackish water (Komárek and Anagnostidis, 2005), and registered to Brazil by Bicudo and Senna (1977), Senna (1996) and Fonseca and Rodrigues (2005) to freshwater environments. In the marine ecosystem it was cited to Rio de Janeiro State both to the plankton (Oliveira et al., 2005) and to the benthos (Iespa and Silva, 2005).

Studies carried out in two farms of L. vannamei in Mexico between 1989 and 1991 showed the presence of toxic algae (Anabaena spp., Anabaenopsis elenkinii and O. limnetica) in the shrimps (Cortés-Altamiro, 1994). These species also occurred in shallow freshwater lakes of Turkey (Karacaoúlu et al., 2004), and in estuarine ecossystem (Serrano et al., 2004; Muthukumar et al., 2007) and in semi-intensive shrimp culture ponds in México (Cortés-Altamirano et al., 1995).

This study showed cyanobacteria occurrence in all farms. The low species number and the dominance of only one specie (P. cf. limnetica) in all ponds showed an impairment of the water quality of the ponds. It can be concluded that the cyanobacteria are important water quality indicator in shrimp ponds in Northeastern Brazil. However, studies for a longer time and physical-chemical data are crucial to the comprehension of these organisms role in these environments.

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Table 1 – Shrimp culture farms in Northeastern Brazil

FARMS (City)	Latitude	Longitude	Survival (%) [+]Min – max	Days of cultivation Min-max	Final Weight (g) Min-max
Ceará State					
Promares, Aquafort and Samarisco (Camocim)	2º54'S	40º50'W	40.46-70.11	102-158	9.73-14.28
Papagaio and AS Marine (Acaraú)	2º50'S	40º07'W	43.62-52.90	120-172	10.23-11.11
Compescal, Cina and Vip Camarões (Aracati)	4º33'S	37º46'W	32.58-52.78	116-142	10.28-11.23
Piauí State					
Camapi, Secom and Camarões do Brasil (Cajueiro da Praia)	2º55'S	41º20'W	52.51-64.10	128-160	10.24-11.04
Rio Grande do Norte State					
Potiporã(*), MRG(*) and Aquática(*) (Pendências)	06º16'S	35º29'W	37.57-66.27	142-174	11.03-13.21

(*) Samples collected during the 2nd e 3rd campaigns. [+]Min-max= Minimum and maximum

Data information: http://www.abccam.com.br/

Table 2. List of species of cyanobacteria and distribuition in Shrimp culture farms in Northeastern Brazil.

State	Ceará									Piauí		Rio Grande do Norte		
Fams	**Promares**	**Aquaforte**	**Samarisco**	**Papagaio**	**A. S. Marine**	**Compescal**	**Cina**	**Vip Camarões**	**Campi**	**Secon**	**Camarões do Brasil**	**Potiporã**	**MGR**	**Aquatica**
DIVISION: CYANOPHYTA														
CLASS: CYANOPHCEAE														
ORDER: CHROOCOCCALES														
Chroococcus sp.							X							
Merismopedia sp.		X												
ORDER: OSCILLATORIALES														
Geitlerinema amphibium (Agardh & Gomont) Anagnostidis			X						X					
Oscillatoria sp.											X			
O. sub-brevis Schmidle	X	X									X			
Pseudoanabaena cf. *limnetica*	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pseudoanabaena sp.	X													
ORDER: NOSTOCALES														
Anabaena constricta Geitler			X											X
A. spiroides Klebahn			X											X
Anabaenopsis sp.							X	X						
Cylindrospermopsis raciborskii (Woloszynska) Seenayya & Subba Raju			X											
Raphidiopsis indica R. N. Singh			X											

Captions to Figures

Figure 1 – Studied area in Northeastern Brazil showing the municipalities where the farms are installed.

Figure 2 – Cyanobacteria average density and standard deviation in the shrimp farm ponds in Northeastern Brazil

Figure 3 – Total density of the cyanobacteria in the intake water point and ponds in shrimp farm from Northeastern Brazil

Figure 4 – Total density of the cyanobacteria in the farms by campaig, during October and November/2003 in the shrimp farm ponds in Northeastern Brazil

Figure 5 – Pseudanabaena cf. limnetica density in the shrimp farm ponds in Northeastern Brazil.

Fig 1.

Cajueiro
da Praia
Acarau
Camocim
Fortaleza
Aracati
Pendências
N
São Luis
Maranhão
Teresina
Ceará
Rio Grande do Norte
Natal
Piauí
Paraíba
João Pessoa
Pernambuco
Recife
Alagoas
Maceió
Sergipe
Aracaju
Bahia
Salvador
Brazil
NE
○ = Municipality of the farms

Fig 2

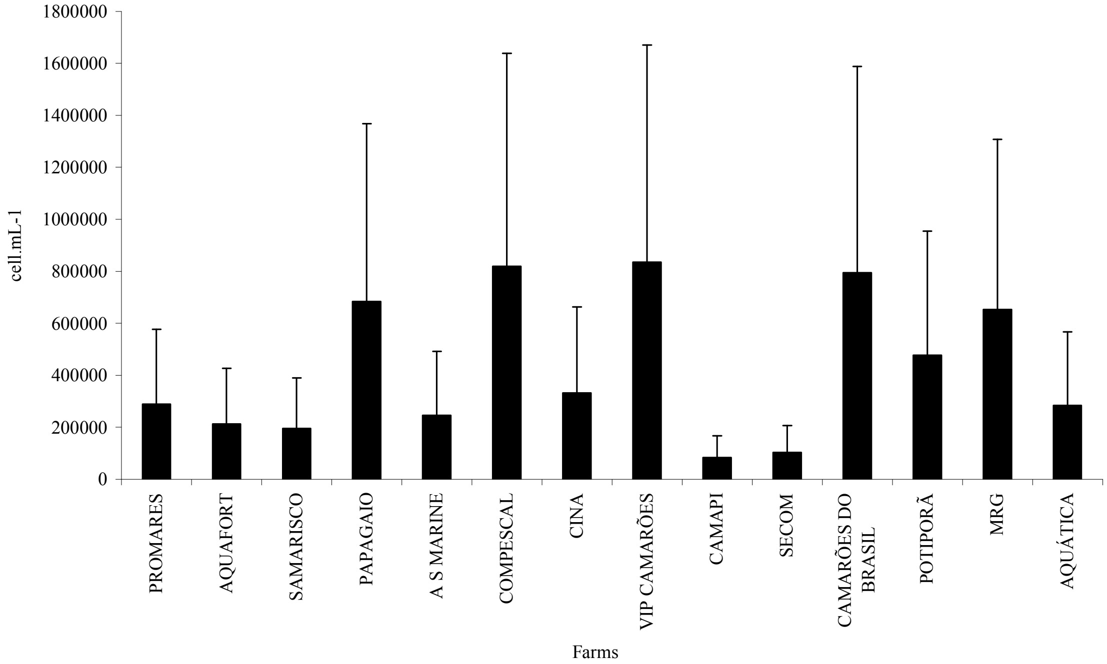

1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
cell.mL-1
PROMARES
AQUAFORT
SAMARISCO
PAPAGAIO
A S MARINE
COMPESCAL
CINA
VIP CAMARÕES
CAMAPI
SECOM
CAMARÕES DO BRASIL
POTIPORÃ
MRG
AQUÁTICA
Farms

Fig. 3

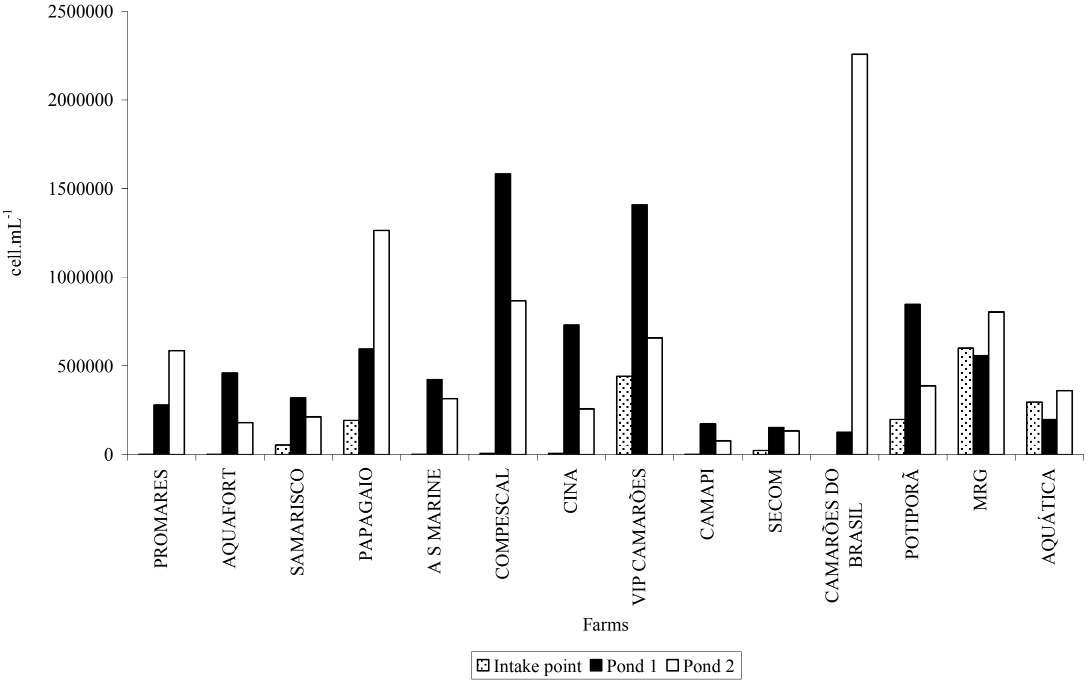
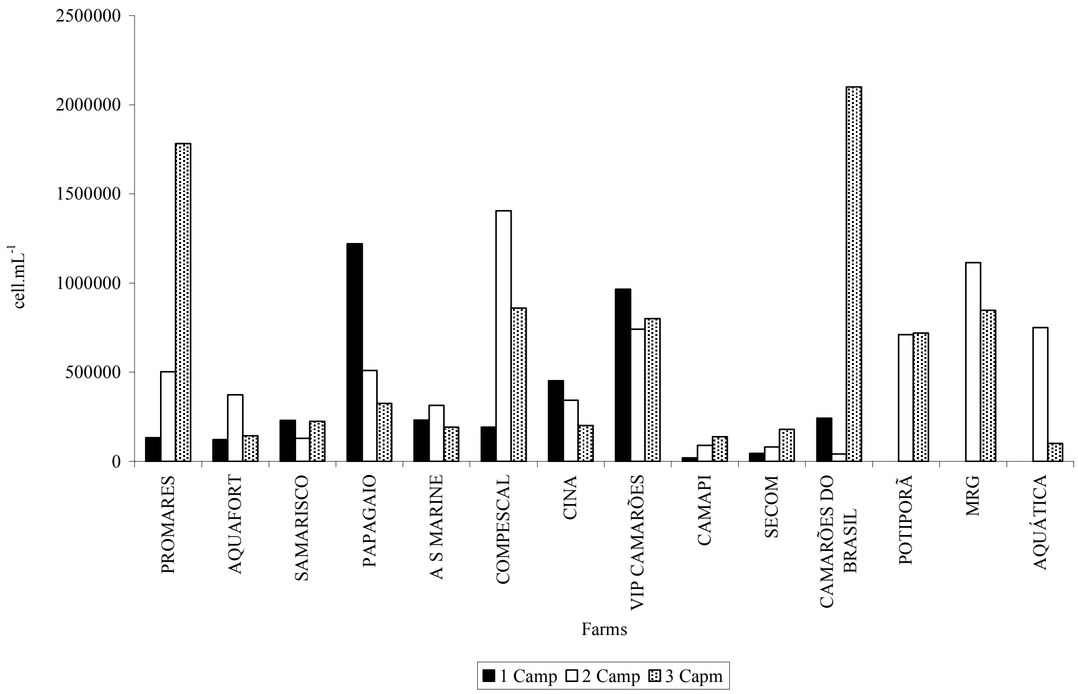

2500000
2000000
1500000
1000000
500000
0
cell.mL-1
PROMARES
AQUAFORT
SAMARISCO
PAPAGAIO
A S MARINE
COMPESCAL
CINA
VIP CAMARÕES
CAMAPI
SECOM
CAMARÕES DO BRASIL
POTIPORÃ
MRG
AQUÁTICA
Farms
Intake point
Pond 1
Pond 2

Fig. 4


2500000
2000000
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500000
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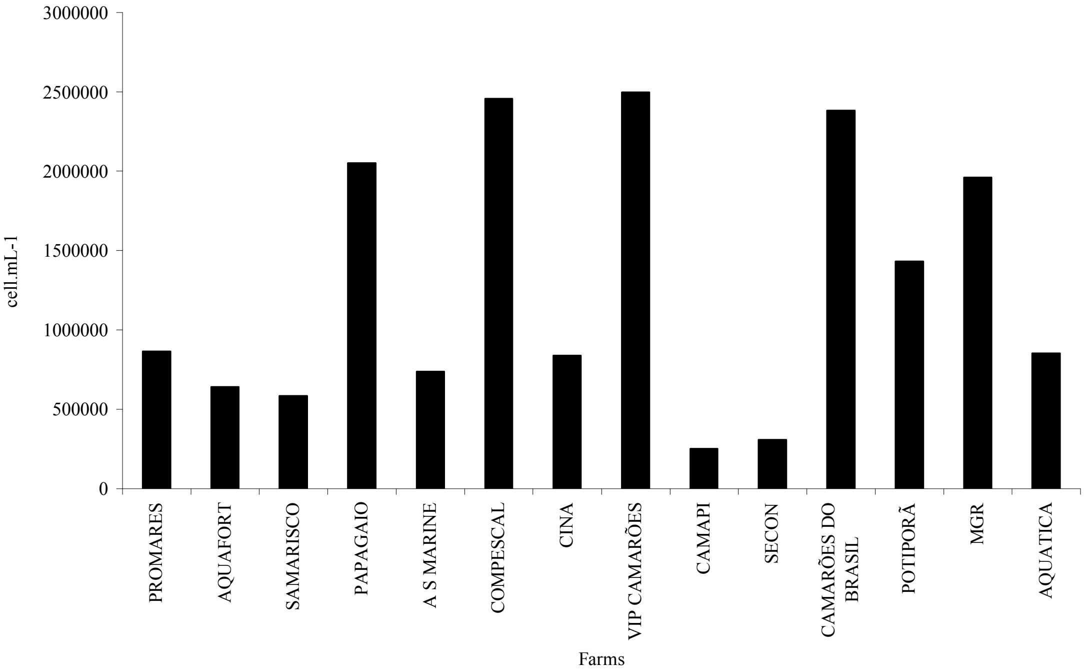
cell.mL-1
PROMARES
AQUAFORT
SAMARISCO
PAPAGAIO
A S MARINE
COMPESCAL
CINA
VIP CAMARÕES
CAMAPI
SECOM
CAMARÕES DO BRASIL
POTIPORÃ
MRG
AQUÁTICA
Farms
1 Camp
2 Camp
3 Capm

Fig. 5


3000000
2500000
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0
cell.mL-1
PROMARES
AQUAFORT
SAMARISCO
PAPAGAIO
A S MARINE
COMPESCAL
CINA
VIP CAMARÕES
CAMAPI
SECON
CAMARÕES DO BRASIL
POTIPORÃ
MGR
AQUATICA
Farms

ARTIGO 3

Zooplankton from Marine Shrimp Culture Ponds in Northeastern Brazil.

A ser submetido à **Aquaculture Research.**

Title:

Zooplankton from Marine Shrimp Culture Ponds in Northeastern Brazil

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Running title: Zooplankton from shrimp ponds

Keywords: Zooplankton, aquaculture, shrimp ponds, *Litopenaeus vannamei*

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Abstract

The zooplankton was studied in 14 commercial shrimp *Litopenaeus vannamei* pond in tropical Brazil to: (1) assess their composition, (2) determine their density, (3) indicate environmental quality. In each farm, two ponds and the water intake point were monitored in 2003. A plankton net 50 μm mesh size was used to collect samples. The zooplankton presented 40 taxa and was essentially composed of typical marine euryhaline species and suspension-feeding forms. In all farms the dominant group was Copepoda with a total of 45%, followed by Protozoa (18%). Among the meroplankton outranked Polychaeta larvae (dominated by spionids), Gastropoda larvae, nauplii of Cirripedia and zoeae of Brachyura. Zooplankton varied from 972 ± 209 ind m^{-3} to $4,235 \pm 2,877$ ind m^{-3}. Copepoda dominance were replaced by protozoan and rotifers as nutrient concentrations increased with the culture period, indicating that zooplankton trophic structure can be strongly affected by the occurrence of eutrophic conditions in shrimp ponds. The tendency of a low species diversity is indicative of an unbalanced hipereuthrophic system decreasing the water quality and the cultured species. These results can be an important appointment to understand the effects of eutrophication in coastal plankton structure and its effects to marine aquatic food web.

Introduction

Shrimp farming in Northeastern Brazil has increased exponentially during the past 10 years from an annual production of about 7,000 tons, produced in less that 1000 ha of pond area in 1998 to over 90,000 tons produced in about 15,000 ha of pond area in 2003 (Madrid, 2004). Although farmed shrimp now represent about 50% of the penaeid shrimp supply, farmers have suffered significant economic losses over the last decade. Reasons for decline include lack of knowledge about farming techniques, poor farm management practices, degradation of environment/water quality through industrial pollution/discharge, and (most importantly), shrimp disease. In Brazil, mortalities of cultured shrimp due to Idiopathic Abdominal Necrosis have resulted in significant economic losses, and it is now spreading throughout Northeastern region.

The water quality associated with aquaculture developments is an important concern globally as a variety of negative environmental impacts on the receiving environment have been documented (Landesman, 1994). Most importantly, it is the water quality that will influence optimal shrimp growth and yield. Classically, an investigation of water quality involves a combination of physical variables and biological indicators (Jones *et al*., 2001). The fact that intensive mariculture often involves the addition of various feeds, fertilizers and chemicals to stabilize the earthen pond bottoms, the use of only classic physicochemical variables to accurately assess the water quality in and around these systems may be insufficient. Additionally, there is still few information on the use of the plankton community as biological indicators of water quality associated with culture systems. Consequently, this research would provide more data on the use of zooplankton as indicators of water quality. The central trophic position occupied by zooplankton makes them potentially valuable indicators of eutrophication, trophic coupling, and overall ecosystem health. Zooplankton assemblages are correlated with N:P ratios serving as a proxy for nutrient status of lakes

(Stemberger & Miller, 1998). Zooplankton clearly contribute to the nutrition of shrimp postlarvae immediately after stocking (Coman *et al*., 2003). Overall, this research will be able to provide useful baseline water quality data that may enable the improvement of farm management processes. Our hypothesis is that the zooplankton community of the ponds is sensitive to eutrophication and that some combination of abundance and diversity measures of this community can be used as water quality indication.

Material and Methods

This research was based in 108 zooplankton samples collected during three campaigns from October 10th to November 19th 2003 in 14 farms that intensively cultivate the marine shrimp *Litopenaeus vannamei*. Campaign 1 was carried out from 19 to 25/October; Campaign 2 from 01 to 07/November; Campaign 3 from 14 to 17/November. In each farm, two ponds and the water intake point were monitored. The studied farms are located in Ceará, Piauí and Rio Grande do Norte states - Brazil (Tab. 1, Fig. 1). The farms produce shrimp by intensive culture (30 to 120 shrimps.m^{-2}), feeding exclusively with balanced ration.

Zooplankton sampling at each station was collected with a standard plankton net with mesh size of 50 micrometers fitted with a flowmeter (Hydrobios, Kiel); 3 minutes horizontal subsurface hauls were made at each pond. Samples were preserved in a 4% buffered formalin/seawater solution. Zooplankton species were identified until the lowest taxonomic unit possible and taxon abundance (per cubic meter) counted under a microscope (1 mL subsample). These samples were taken with a Stempel-pipette of each the entire sample (250 mL).

The Shannon index (H') was applied for the estimation of zooplankton community diversity based on log_2 (Shannon, 1948). Evenness was calculated according to Pielou (1967).

Multivariate procedures included: 1) classification (cluster analysis) on the sample- species data matrix using the Pearson moment-product correlation index and the Weighted Pair Group Method-Arithmetical Averages (WPGMA) link method for the dendrograms (Legendre & Legendre, 1998). A cophenetic value matrix was applied to test the goodness of fit of the cluster analysis to the data (Rohlf & Fisher, 1968). 2) A principal components analysis (PCA) was used to assess farms similarities. The computation was based on a matrix of correlation (Pearson moment product) between the objects after log (x+1) tranformation, and then factored, and a plot was constructed, showing the objects in two-dimensional space.

Results

The zooplankton presented 40 taxa (Table 1) composed by Sarcomastigophora, Cnidaria, Nematoda, Rotifera, Mollusca, Annelida, Crustacea, Bryozoa and Chordata. Copepoda presented highest richness with 16 species (corresponding to 44% of relative abundance), followed by Protozoa (18%) and Rotatoria (12%) (Fig. 2).

Among Copepoda predominated *Parvocalanus crassirostris, Acartia lilljeborgi, Oithona oswaldocruzi, Oithona hebes* and *Euterpina acutifrons*. These species are the Brazilian eurihaline-estuarine indicators. The Protozoa presented high numbers of atecate ciliata besides the presence of tintinnina with the species *Tintinnopsis* spp. and *Favella ehrenbergi* which characterize euthrophic systems. Among the rotifers outranked *Brachionus plicatilis* in the aquaculture ponds.

The meroplankton was represented by Polychaeta larvae (dominated by spionids), Gastropoda and Bivalvia larvae, nauplii of Cirripedia and zoeae of Brachyura. Many stages of Nematoda were found at Cina and Papagaio farms and belonged to *Ancylostoma duodenale.*

In terms of frequency of occurrence outranked nauplii of Copepoda, Oithona oswaldocruzii with more than 70%, followed by Polychaeta larvae (65%), Atecate cukuates (64%), Nematode (54%) and Tintinnopsis spp. with 46% (Fig. 3).

Species diversity was low and varied from 1.26 $bits.ind^{-1}$ (Aquafort farm) to 1.75 $bits.ind^{-1}$ (Promares farm) (Fig. 4), with an average of 1.57 ±1.13 $bits.ind^{-1}$. Minimum evenness was 0.44 registered at Aquafort farm due the dominance of few species (mainly atecate ciliata and Copepoda nauplii) and the maximum was 0.6 at Vip Camarões farm (Fig. 4), with an average of 0.53±0.05.

Zooplankton total density varied from 3,875 $org.m^{-3}$ (Aquática farm) to 12,706 $org.m^{-3}$ (Compescal farm) with an average of 2255±975 $ind.m^{-3}$ (Fig. 5).

The intake areas presented better water quality than most ponds, in which dominated many times organic pollution indicators (atecates ciliates, rotifers, polychaeta larvae, nematode, among others).

In the Cina farm, it was registered a Mysis stage with ectoparasites protozoan as *Vorticella* spp. These parasites affect negatively the molts and the development of the infected organisms. This fact was also observed in the farm Papagaio where parasitic nematode was registered.

The stations dendrogram showed two groups (Fig. 6), one formed by the intake point of Campaign 1 and 3 of all farms and the other by the ponds 1 and 2 of all farms. Intake point of Campaingn 2 from all farms was separeted.

The Principal Components Analysis presented four groups. Group 1 was formed by Samarisco, Camarões do Brasil and Aquatica farms that presented high densities of atecates ciliates and copepods nauplii. Group 2 was composed by MRG and Papagaio farms which was characyerized by higher densities and *Brachionus plicatilis* and poliquets larvae were abundant. Group 3 by ASMarine and Vip Camarões farms with lower densities and mainly represented by *Oithona oswaldocruzi* both adults and nauplii; and Group 4 all the other seven farms with average densities (Fig. 7).

Discussion

The use of physicochemical indicators exclusively to asses the water quality of intensive mariculture system is insufficient particularly if there is an investigation into the extent of the influence of the farm wastewater on the immediate environs. Previous studies that conclude that the use of traditional water quality indices to determine the effect of aquaculture effluent on the receiving environment is mainly limited to areas near to the discharge point (Hensey, 1991; Samocha & Lawrence, 1997; Samocha et al., 2004).

We considered zooplankton indices to be useful water quality indicators for the shrimp culture facility and its immediate environs. This was on the basis that there were fairly distinct patterns in the species composition and abundance as the water quality changed spatially and temporally. This may be attributed to the fact that the zooplankton community itself responds directly or indirectly to changes in the physicochemical variables and the availability of phytoplankton food (Raymont, 1980) and is therefore less affected by manipulation via farm management processes.

Thus our study examined the seasonal and tidal variation of microzooplankton in Northeastern shrimp farms to develop a more comprehensive understanding of the zooplankton role in these conditions. In general, little is known about the zooplankton dynamics in tropical estuaries, and according to Buskey (1993), zooplankton rarely have been studied concurrently in tropical or temperate estuaries, even less studies exists on shrimp ponds.

Studies of zooplankton in shrimp ponds have shown that these are complex assemblages with rapid temporal changes in structure (Coman *et al*., 2003). The main factors influencing these changes are variations in source of food, predation and the influences of variations in physical and chemical water quality parameters (Preston *et al*., 2003). The results here described reveals indirectly that nutrient input affected both density and the relative species composition of the zooplankton community. Therefore zooplankton assemblages essentially composed of typical marine euryhaline species could be an excellent bioindicador of water quality of shrimp ponds.

The dominant taxa were Copepoda and the most representative species are eurihaline-estuarine indicators formed by *Parvocalanus crassirostris, Acartia lilljeborgi, Oithona oswaldocruzi, Oithona hebes* and *Euterpina acutifrons* (Björnberg, 1981; Neumann-Leitão *et al*., 1999).

Of the copepods registered, *Acartia lilljeborgi* and *Parvocalanus crassirostris* were abundant. *Acartia lilljeborgi* had an important role in the ponds and this may be related to the high amount of detritus that is consumed by this species, as has been demonstrated through stable isotope measurements and feeding experiments performed in laboratory and in situ (Schwamborn, 1997; Schwamborn *et al.*, 1999). *Parvocalanus crassirostris* was important in most farms and it is very common in most Brazilian estuaries (Björnberg, 1981) even those dramatic impacted (Schwamborn *et al*., 2004; Silva *et al*., 2004). *Parvocalanus crassirostris* feeds significantly on picoplankton and nanoplankton and behaves as opportunistic particle feeder, showing higher consumption rates upon the most abundant cells (2-5 µm nanoplankton) (Calbet *et al.*, 2000). Generally it is an abundant species in euthrophic systems.

Copepods and other crustaceans, larvae of polychaetes, larvae of insects, mollusks (Bivalvia and Gastropoda larvae), ostracods, rotifers have been considered the most important sources of food for shrimp (Rubright *et al*., 1981; Schoreder, 1983; Allan *et a*l., 1995, among others). The assemblages found in the studied ponds have a variety of roles within the pond ecosystem. Grazing zooplankton influences the dynamics of pond phytoplankton (Coman *et al*., 2003). Predation of zooplankton by shrimp (Martinez-Cordova *et al*., 1998) may transfer a significant proportion of the nutrients from natural biota to the shrimp (Anderson *et al*., 1987).

Another abundant group in the ponds were the ciliated protozoa which play an important role in the energy flow of aquatic ecosystems, as predators of bacteria, algae, and fungi, and as a food source for metazoa, such as fish and shrimp larvae (Curds, 1992; Nagano & Decamp, 2004). Furthermore, the relative abundance and diversity of ciliates have been used as indicators of water quality and ecosystem dynamics (Foissner 1988; Curds 1992; Decamp *et al*. 1999). However, their occurrence and role in shrimp production systems have seldom been investigated. Bratvold *et al.* (1999) reported that the zooplankton from intensive shrimp production systems were dominated by ciliates, at least during part of the production cycle. Decamp *et al*. (2007) studying shrimp culture ponds found that free-swimming ciliates were dominant in the early stages of production and showed that ciliates could reach very high concentrations, that is, over 6000 cells mL^{-1}, within zero-water exchange shrimp production systems. These concentrations are closer to those recorded in wastewater treatment plants,that is, 15,000–60,000 cells mL^{-1} (Curds 1992; Abraham *et al.,* 1997), than those recorded in eutrophic lakes, that is, 155–200 cells mL^{-1} (Laybourn-Parry, 1992) or coastal marine sites, that is, 2–92 cells mL^{-1} (Leakey *et al*., 1992).

In the recent past, researchers drew attention to the presence of large numbers of ciliates in intensive shrimp production systems (Bratvold *et al*., 1999) and to the importance of ciliates in the diet of shrimp larvae (Thompson *et al*., 1999), and the influence of salinity (Dechamp *et al*., 2003).

Among ciliates, the tintinnids constitute important component of the planktonic microprotozoan community in most marine environments (Beers *et al*., 1982; Pierce and Turner, 1992, 1993; Cordeiro *et al*., 1997; Tillmann, 2004), and they can be important occasionally in estuarine waters (Barría de Cao, 1981; Urrutxurtu, 2004).

Some species have an apparent cosmopolitan distribution in the seas and oceans (Marshall, 1969). *Favella ehrenbergii* has been commonly found in costal and estuarine areas in Brazil, with a high density in some periods (Neumann-Leitão *et al.*, 1992; Lopes, 1994; Eskinazi-Sant'Anna & Tundisi, 1996; among others). The singular higher values of *F. ehrenbergii* densities were responsible for the structure disturbance of the microzooplankton community (negative contribution to the Shannon's diversity index) in the present study. The diet of *F. ehrenbergii* is composed mainly of nanoflagellates (Bernard & Rassoulzadegan, 1993). This species occurs in regions with high temperature and wide salinity ranges (Godhantaraman & Uye, 2003).

The high density of *Brachionus plicatilis* in the aquaculture ponds is a positive condition as rotifers are valuable live food for larval fish and crustacean culture and also have been used as indicators of throphy (Sharma, 1983, Saksena, 1987). Several characteristics of rotifers, including their nutritional quality, body size and relatively slow motility have contributed to their usefulness as good prey for active larvae (Snell & Carrillo, 1984). The rotifer *Brachionus plicatilis* has been most widely used as essential food source in raising marine fish, shrimp and crab larvae due to its tolerance to the marine environment (Lubzens, 1987). The rotifer *B. plicatilis* is an euryhaline species (Koste, 1978) and in nature, density peaks of these species are associated with high eutrophication near village and/or processing plants of aquatic and/or poultry products (Fenggi, 1996). *B. plicatilis* and others rotifers species dominated the estuarine region of the Ipojuca river (Northeastern Brazil) that receives high sewage loads from many cities and industries (Neumann-Leitão *et al*., 1992). Rotifers show preference for the small-size fraction 1–5 mm of phytoplankton and are reported to graze more efficiently than ciliates (Laybourn-Parry 1992). Their occurrence and abundance might have, at times, impacted the size structure of phytoplankton (through high grazing rates) and the occurrence of algivorous ciliates (through competition).

Many stages of Nematoda, found at Cina and Papagaio farms belonged to *Ancylostoma duodenale* and according to Rey (2002) the larvae develop in the aquatic environment, at the rainy season, between temperatures between 23 and 30^{o}C and the adults develop well in humid soil rich in organic residuals.

Neumann-Leitão & Matsumura-Tundisi (1998) reported the importance of the marine flux renewing the zooplankton community in a highly impacted estuary in Northeastern Brazil.

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Figure legends

Figure 1 – Shrimp ponds localization in Northeast Brazil

Figure 2 – Relative abundance of total zooplankton from shrimp farms in Northeast Brazil.

Figure 3 – Frequency of ocurrence of zooplankton from shrimp farms in Northeast Brazil.

Figure 4 – Species diversity and evenness of zooplankton from shrimp farms in Northeast Brazil.

Figure 5 – Density of zooplankton from shrimp farms in Northeast Brazil.

Figure 6 – Dendrogram from the stations based on Pearson correlation index and WPGMA link method. C=campaign

Figure 7 – Principal Components Analysis of the 14 shrimp farms in Northeastern Brazil.

Table 1 – Sinopse of zooplankton from shrimp farms in Northeastern Brazil

Filo Sarcomastigophora	Filo Crustacea
Subfilo Sarcodina	Classe Copepoda
Superclasse Rhizopoda	*Pseudodiaptomus marshi* Wright, 1936
Ordem Testacea	*Parvocalanus crassirostris* F. Dahl, 1894
Arcella vulgaris Ehrenberg, 1838	*Centropages velificatus* Dana, 1849
Ordem Foraminifera	*Calanopia americana* F. Dahl, 1894
Ordem Tintinnida	*Acartia lilljeborgi* Giesbrecht, 1892
Tintinnopsis spp.	*Temora stylifera* (Dana, 1849)
Favella ehrenbergii (Claparéde et Lachmann 1858)	*Temora turbinata* Dana, 1849
Filo Cnidaria	*Corycaeus* sp.
Ordem Hydroida	*Oithona hebes* Giesbrecht, 1891
Filo Nematoda	*Oithona nana* Giesbrecht, 1892
Filo Rotifera	*Oithona oswaldocruzi* Oliveira, 1945
Superordem Digononta (Bdelloidea)	*Euterpina acutifrons* (Dana, 1852)
Rotatoria sp	*Triguiopus* sp.
Superordem Monogononta	Harpacticoida (outros)
Ordem Ploimida	Monstriloida
Epiphanes macrourus	Classe Cirripedia
Brachionus plicatilis (O. F. Muller, 1786)	Classe Malacostraca
Keratella tropica Apstein, 1907	Ordem Decapoda
Keratella americana Carlin 1943	Infraordem Brachyura
Lecane spp	Filo Bryozoa
Ordem Gnesiotrocha	Ordem Cheilostomata
Conochilus sp	*Membranipora* sp (larva)
Filo Mollusca	Filo Chordata
Classe Gastropoda	Classe Larvacea
Classe Bivalvia	Família Oikopleuridae
Filo Annelida	*Oikopleura* sp
Classe Polychaeta	Família Ascidiacea


N
Cajueiro
da Praia
Acarau
Camocim
Aracati
Pendências
SÃO LUIS
FORTALEZA
MARANHÃO
TERESINA
CEARÁ
RIO GRANDE
DO NORTE
NATAL
PARAÍBA
JOÃO PESSOA
PIAUÍ
PERNAMBUCO
RECIFE
ALAGOAS
MACEIÓ
SERGIPE
ARACAJÚ
BAHIA
SALVADOR
Brazil
NE
– Municipality of the farms

Fig. 1

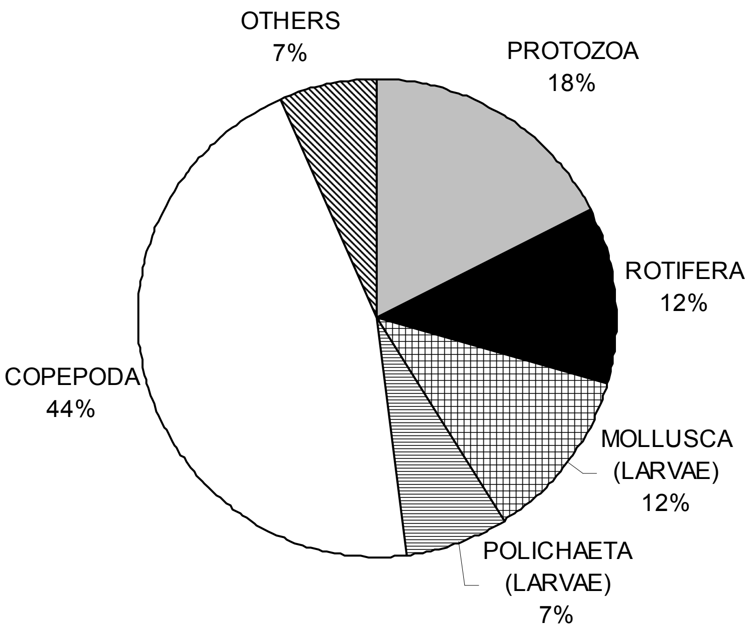

OTHERS
7%
PROTOZOA
18%
ROTIFERA
12%
MOLLUSCA
(LARVAE)
12%
POLICHAETA
(LARVAE)
7%
COPEPODA
44%

Fig. 2

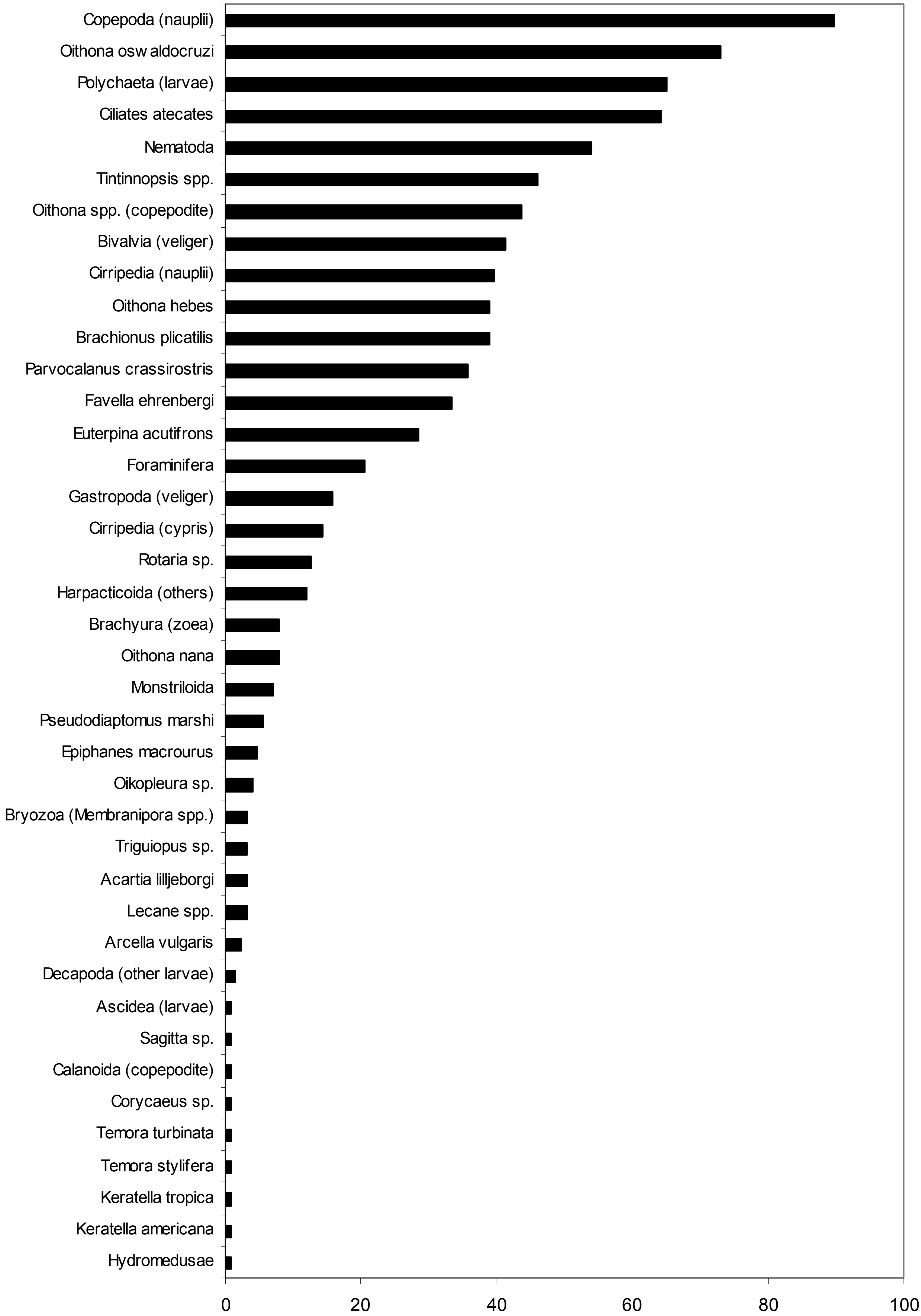
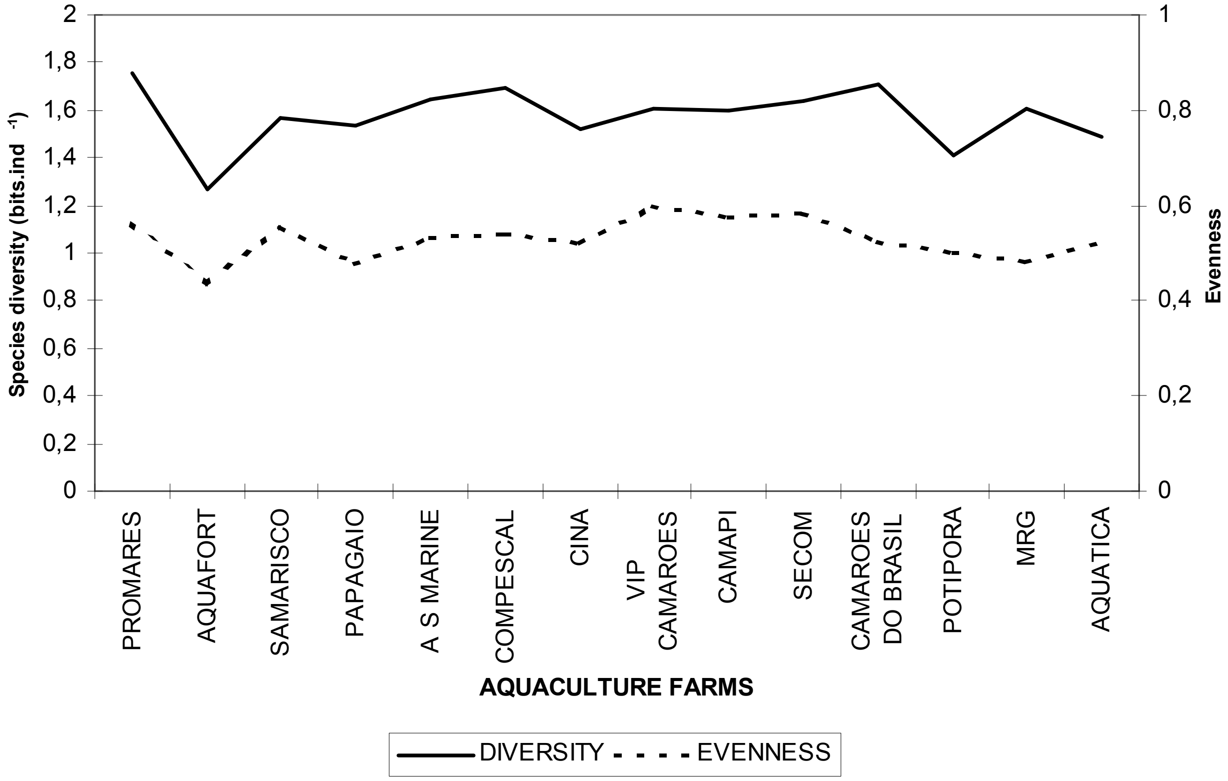

Copepoda (nauplii)
Oithona oswaldocruzi
Polychaeta (larvae)
Ciliates atecates
Nematoda
Tintinnopsis spp.
Oithona spp. (copepodite)
Bivalvia (veliger)
Cirripedia (nauplii)
Oithona hebes
Brachionus plicatilis
Parvocalanus crassirostris
Favella ehrenbergi
Euterpina acutifrons
Foraminifera
Gastropoda (veliger)
Cirripedia (cypris)
Rotaria sp.
Harpacticoida (others)
Brachyura (zoea)
Oithona nana
Monstriloida
Pseudodiaptomus marshi
Epiphanes macrourus
Oikopleura sp.
Bryozoa (Membranipora spp.)
Triguiopus sp.
Acartia lilljeborgi
Lecane spp.
Arcella vulgaris
Decapoda (other larvae)
Ascidea (larvae)
Sagitta sp.
Calanoida (copepodite)
Corycaeus sp.
Temora turbinata
Temora stylifera
Keratella tropica
Keratella americana
Hydromedusae
0
20
40
60
80
100

Fig. 3


2
1,8
1,6
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1
0,8
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0
Species diversity (bits.ind -1)
1
0,8
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Evenness
PROMARES
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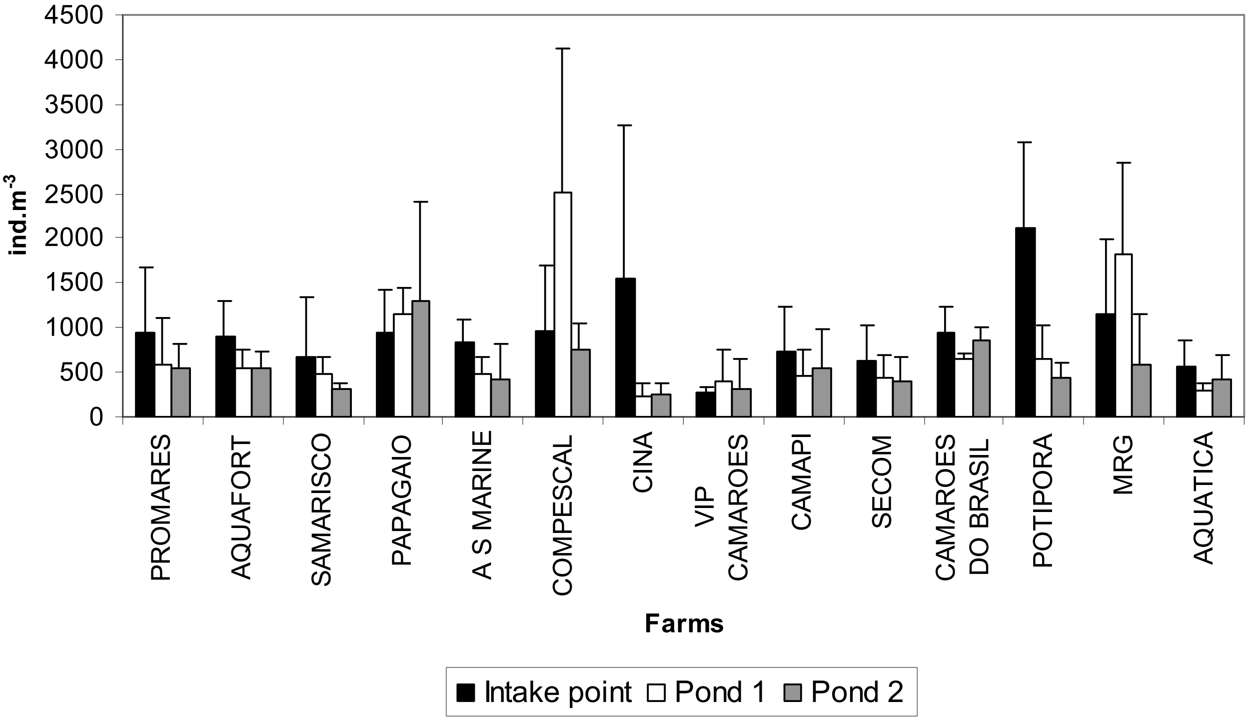
SAMARISCO
PAPAGAIO
A S MARINE
COMPESCAL
CINA
VIP CAMAROES
CAMAPI
SECOM
CAMAROES DO BRASIL
POTIPORA
MRG
AQUATICA
AQUACULTURE FARMS
DIVERSITY
EVENNESS

Fig. 4


4500
4000
3500
3000
2500
2000
1500
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500
0
ind.m-3
PROMARES
AQUAFORT
SAMARISCO
PAPAGAIO
A S MARINE
COMPESCAL
CINA
VIP CAMAROES
CAMAPI
SECOM
CAMAROES DO BRASIL
POTIPORA
MRG
AQUATICA
Farms
Intake point
Pond 1
Pond 2

Fig. 5

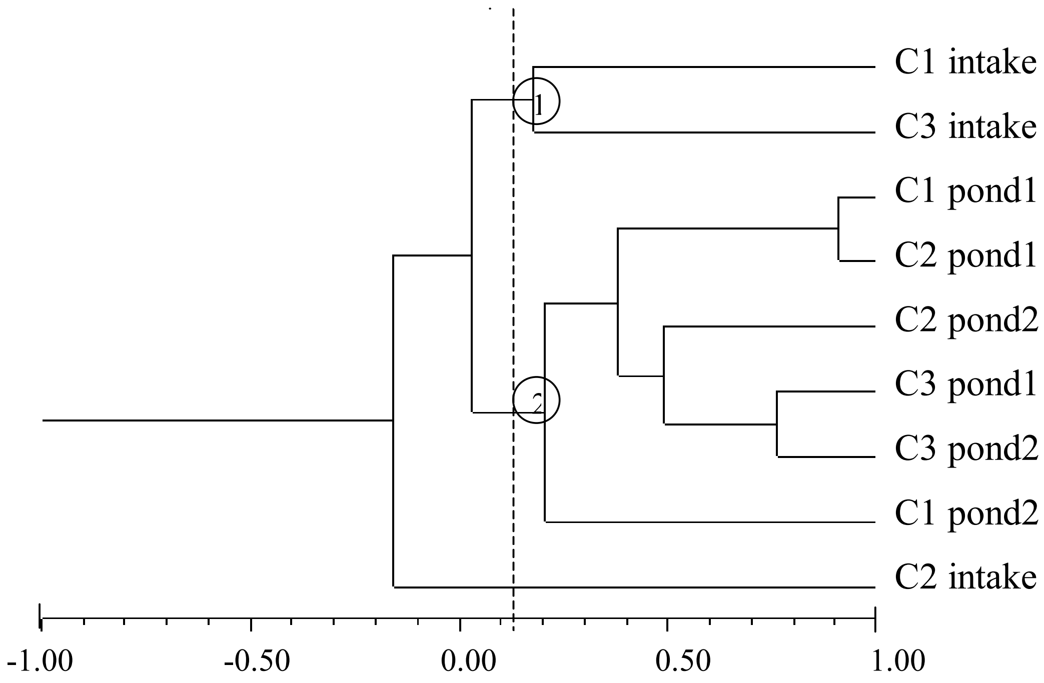
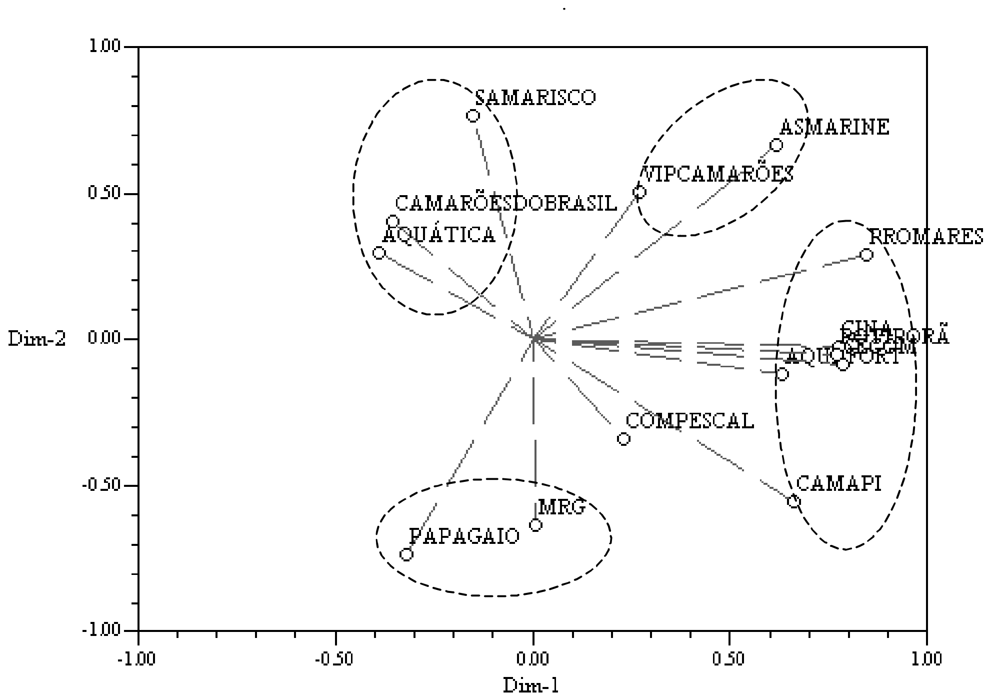

C1 intake
C3 intake
C1 pond1
C2 pond1
C2 pond2
C3 pond1
C3 pond2
C1 pond2
C2 intake
1
2
-1.00
-0.50
0.00
0.50
1.00

Fig. 6


SAMARISCO
ASMARINE
VIPCAMARÕES
CAMARÕESDOBRASIL
AQUÁTICA
RROMARES
CINA
AQUI
FORT
COMPESCAL
CAMAPI
MRG
PAPAGAIO
Dim-2
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1.00
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Fig. 7

7 Considerações Finais

Diante da visível importância socioeconômica da Carcinicultura para o Brasil, sobretudo para a região Nordeste, percebe-se a escassez de estudos relacionados à qualidade da água utilizada nos cultivos brasileiros. A degradação ambiental e as patologias infecciosas que têm afetado essa atividade levaram a sérios prejuízos, como por exemplo, a diminuição da produção (KAUTSKY *et al.*, 2000; BACHÉRE, 2000; PÁEZ-OSUNA, 2001). A apreensão com relação aos impactos é evidente e vários trabalhos tem sido publicados revelando as conseqüências da carcinicultura intensiva em várias regiões do mundo (RANA, 1997; PRIMAVERA, 1997, 1998; JONES *et al.*, 2001; PÁEZ-OSUNA, 2001; RÖNNBÄCK, 2002).

A preocupação da Associação Brasileira de Criadores de Camarão (ABCC) com a implantação de boas práticas de manejo e produção, sinaliza para a necessidade de um monitoramento cada vez mais eficiente da cadeia produtiva. Sendo assim, os cuidados com a manutenção da qualidade ambiental das áreas de cultivo, em sua grande maioria localizadas em manguezais, são de vital importância para a Carcinicultura, assim como para esses ecossistemas. Pois, a saúde dos camarões está intrinsecamente ligada ao meio em que vivem.

O cultivo intensivo de organismos aquáticos envolve a adição de fertilizantes, adubos e diversos compostos químicos. Apesar da existência de leis internacionais regulamentando a Carcinicultura, os testes de monitoramento avaliam basicamente parâmetros físico-químicos, considerando apenas a clorofila como fator biótico a ser analisado (PRIMAVERA *et al.*, 1993; BOYD, MASSAUT, 1999; BOYD, GOUTIER, 2000; THAKUR, LIN, 2003; CASILLA- HERNÁNDEZ *et al.*, 2007). A ocorrência da Mionecrose Infecciosa nos estados brasileiros que apresentam as maiores produtividades (Piauí, Ceará e Rio Grande do Norte) revela a fragilidade do sistema de cultivo e a ineficiência do monitoramento priorizando análises físico-químicas.

O uso da biomassa fitoplanctônica como um indicador para o cultivo de camarões apresenta algumas limitações. Primeiramente, os valores de clorofila podem ser superestimados em áreas com densas populações de macroalgas. Além disso, a presença de espécies coloniais de microalgas pode superestimar a contribuição desta fração na biomassa total. O tamanho e a fração do fitoplâncton são importantes em nível microscópico na determinação da qualidade da águas e não existem resultados que revelem as variações diárias da biomassa e composição desta comunidade e suas relações com a luz e nutrientes em fazendas de cultivo de camarões (BOYD, 1990; ZIEMANN *et al*., 1992; HOPKINS *et al*., 1993; BARRAZA-GUZMÁN, 1994; BUFFORD, 1997, 2005; JOHNSTON *et al*., 2002; YUSOFF *et al*., 2002; ALONSO-RODRÍGUEZ, PÁEZ-OSUNA, 2003). Assim, é importante o conhecimento da composição das espécies e sua dinâmica, que varia sob a influência de fatores como luz temperatura e concentração de nutrientes (YUSOFF, MCNABB, 1997; YUSOFF *et al*., 2002).

Os resultados de índices planctônicos como bioindicadores apresentados neste trabalho, propõem a utilização da composição desses organismos como ferramenta auxiliar no monitoramento da qualidade da água nos viveiros de cultivo de camarão. Já que o fito e zooplâncton respondem a condições como diminuição de oxigênio dissolvido, altos níveis de nutrientes, contaminação por substâncias tóxicas, baixa qualidade ou escassez de alimento ou predação, funcionando como um elo de ligação entre os nutrientes disponibilizados nos viveiros e os camarões, um bom monitoramento das condições dos viveiros pode ser derivado da observação de indicadores, tais como biomassa, abundância e diversidade de espécies (BURFORD, 1997; PHILLIPS; PRIMAVERA, 1998; JOHNSTON *et al.*, 2002).

O fitoplâncton analisado nas 14 fazendas amostradas apresentou um total de 51 espécies identificadas, sendo 57% diatomáceas. Estas, geralmente compreendem mais de 80% do fitoplâncton marinho tropical brasileiro e são consideradas desejáveis na comunidade estuarina, particularmente as diatomáceas cêntricas, como a espécie *Cyclotella meneghiniana*, que apresentam valor diferenciado na cadeia alimentar (BOYD, 1990; ESKINAZI-LEÇA *et al*., 2000). Entretanto, mesmo proporcionando um alto índice de riqueza taxonômica, as diatomáceas não apresentaram densidades significativas no presente trabalho, sendo ultrapassadas por clorofíceas unicelulares, dinoflagelados e cianobactérias.

Em áreas com temperatura da água e luminosidade altas, como o Nordeste brasileiro, a concentração de nutrientes e suas variações são importantes fatores ambientais que influenciam a dominância de vários grupos taxonômicos, sendo respostas úteis como indicadoras do status do ambiente (MORAIS, 2002; YUSOFF *et al*., 2002). Alguns estudos demonstram que os cultivos de camarões têm sido dominados por dinoflagelados, diatomáceas e cianobactérias (BURFORD, 1997; TOOKWINAS, SONGSANGJINDA, 1999; ALONSO-RODRÍGUEZ, PÁEZ-OSUNA, 2003). De fato, em todas as amostragens realizadas durante o presente estudo houve dominância de clorofíceas (*Chlorella* sp.), seguida de cianobatérias (*Pseudoanabaena limnetica* cf.), dinoflagelados (*Scrippsiella trochoidea* e *Gymnodinium* sp.) e diatomáceas (*C. meneghiniana*). Este resultado pode estar relacionado ao fornecimento excessivo de nutrientes, fato freqüente nas regiões costeiras, e mais acentuado com os adubos e fertilizações dos viveiros, promovendo florações de algas e alterações na composição do fitoplâncton.

O fitoplâncton foi dominado por *Chlorella* sp. em nove das 14 fazendas amostradas, nas cinco fazendas restantes *P.* cf *.limnetica* apresentou as maiores densidades. As florações existem como acumulações massivas de uma única ou até duas espécies que coexistem com densidades de 10^4 – 10^6 céls mL^{-1}, e as espécies nocivas são de 95-99% da biomassa residente.

Apesar dos altos valores de clorofíceas, na maioria das fazendas os índices de diversidade foram baixos, sendo os menores nas fazendas Camarões do Brasil (0,174 bits ind^{-}

^{1}) e Aquafort (0,504 bits ind^{-1}). Estes valores devido à abundância de *Chlorella* sp. e *P.* cf. *limnetica*, revelam o desequilíbrio no ambiente. A menor equitabilidade foi registrada na fazenda Camarões do Brasil (0.17), causada pela dominância dos táxons supracitados, e o máximo foi de 0.99 na fazenda MRG, onde o ecossistema apresentou melhor qualidade da água, contudo com condições pobres.

A capacidade de adaptação a condições ambientais extremas das cianobactérias pode levar a substituição de espécies dominantes pode ocorrem ao longo de períodos de baixo hidrodinamismo. Com a eutrofização, populações de diatomáceas decrescem e outros grupos, como dinoflagelados e cianobactérias persistem (ALONSO-RODRÍGUEZ, PÁEZ-OSUNA, 2003). Este comportamento pode apresentar alterações devido ao fotoperíodo, fluxo de entrada de água e os ciclos de produção, por isso, um estudo que abranja todo o ciclo de engorda dos camarões faz-se necessário para a compreensão da dinâmica fitoplanctônica de forma mais completa.

De forma geral a densidade do fitoplâncton foi mais alta nos viveiros que nos canais de captação de água. Esta condição não foi observada nas fazendas MRG e Aquática. Na fazenda Aquática o viveiro 1, sem contaminação, foi o ponto com menor densidade. Enquanto que na MRG esta condição ocorreu no viveiro 2, contaminado, com uma diferença de aproximadamente 100.000 células a menos que na captação e viveiro 1. Com relação às diferenças de densidades entre os viveiros, sete fazendas apresentaram densidades mais altas no viveiro 1 e sete no viveiro 2, não possibilitando uma indicação de relação entre as densidades e a presença de IMN nos viveiros. As maiores diferenças, neste caso, foram observadas na fazenda Camarões do Brasil, com densidade de 277.204 cel.mL^{-1} no viveiro 1 e 5.607.231 cel.mL^{-1} no viveiro 2, valores extremamente altos.

Com relação ao período de amostragem, observou-se o aumento da densidade ao longo das campanhas. Durante a 1ª campanha 9.904.695 cel.mL^{-1} foram registradas. Este valor elevou-se para quase o dobro na segunda campanha (17.707.496 cel.mL^{-1}) e decresceu na 3ª campanha para 13.676.422 cel.mL^{-1}. Este fato pode ser relacionado ao tempo de cultivo e, conseqüentemente, a estabilidade da água, necessitando ser mais bem investigado.

A composição taxonômica, os baixos índices de diversidade e as elevadas densidades observadas no fitoplâncton das fazendas de cultivo de camarão marinho do Nordeste brasileiro durante o presente estudo, revelam que a água utilizada nos viveiros apresenta-se em processo de eutrofização.

As modificações nas comunidades fitoplanctônicas consideradas reflexo das condições físico-químicas da água, são úteis na indicação de eutrofização. Contudo, essas alterações influenciam, sobremaneira, todos os elos da teia trófica aquática. No caso do zooplâncton, consumidores de primeira ordem, essas modificações também possibilitam a formação de uma ferramenta adicional na confirmação da qualidade da água, sendo esta categoria de organismos utilizada de forma simples e efetiva para o monitoramento ambiental.

Os 40 táxons zooplanctônicos identificados no presente estudo foram tipicamente marinhos e eurialinos, incluídos nos filos Sarcomastigophora, Cnidaria, Nematoda, Rotifera, Mollusca, Annelida, Crustacea, Bryozoa e Chordata. Já o meroplâncton, foi representado por fases larvais de Gastropoda, Bivalvia, Polychaeta e Crustacea.

A dominância dos Copepoda, tanto em riqueza, com 16 espécies, como em abundância, representando 44% da densidade, principalmente os náuplios e copepoditos, revela um ambiente rico em alimento vivo para os camarões. Contudo, a ocorrência em grande densidade de *Parvocalanus crassirostris* e *Acartia lilljeborgi*, evidencia estresse ambiental. *P. crassirostris* é uma espécie abundante em estuários brasileiros, inclusive àqueles eutrofizados (SCHWAMBORN *et al*., 2004; SILVA *et al*., 2004). *A. lilljeborgi*, está associada a uma grande quantidade de detritos alimentares (SCHWAMBORN, 1997; SCHWAMBORN *et al*., 1999). Além das espécies citadas, ocorreram ainda, *O. oswaldocruzi,* *O. hebes* e *Euterpina acutifrons*. Pode-se inferir que existe uma alta disponibilidade de alimentos vivos nos viveiros, que juntamente com a alta concentração de nutrientes e fitoplâncton, tornaria o ambiente um local favorável ao desenvolvimento dos camarões, mas parece que a partir de um determinado período do ciclo de vida a fração planctônica já não é importante ao cultivo, tornando-se os excessos em problemas ambientais.

A presença do filo Protozoa, com abundância relativa de 18%, tanto nas amostras da água de captação quanto dos viveiros, principalmente nas fazendas Secom e Aquafort, corrobora a necessidade de melhoria na qualidade da água dos cultivos. Apesar de pouco se conhecer sobre o papel desses organismos dentro dos viveiros, com informações apenas sobre sua ocorrência e densidade (BRATVOLD *et al.*,1999; DECAMP *et al.*, 2003, 2007), sabe-se que os ciliados atecados e os tintinídeos *Tintinnopsis* spp. e *Favella ehrenbergi* são organismos característicos de ambientes eutrofizados e com poluição orgânica. Estes protozoários são utilizados como bioindicadores da qualidade da água e dinâmica de ecossistemas e podem favorecer o controle do bacterioplâncton compondo uma forma adicional de alimento para as formas jovens de camarão (FOISSNER, 1988; CURDS, 1992; DECAMP *et al.*, 1999). Contudo, em quantidades elevadas como as observadas no presente estudo, indicam um ambiente bastante enriquecido com matéria orgânica e sinalizam para o cuidado no descarte de seus efluentes, que podem causar impacto ambiental nos corpos d'água receptores.

Vale ressaltar ainda, a presença dos rotíferos, que contribuíram com 12% da densidade total, destacando-se *Brachionus plicatilis.* Esta espécie possui grande interesse à aqüicultura, pois é cultivada no mundo todo como alimento para larvas de peixes e camarões, devido a sua qualidade nutricional, dimensões e mobilidade, contribuindo para a atividade predatória de organismos em estágio larval (SNELL, CARRILLO, 1984; LUBZENS, 1987; SAKSENA, 1997). Entretanto, picos de densidades de *B. plicatilis* são associados à poluição orgânica em regiões próximas a cidades e baixa qualidade da água em viveiros de camarões no nordeste brasileiro (PARANAGUÁ, NEUMANN-LEITÃO, 1980; 1981; FENGGI, 1996; NEUMANN-LEITÃO *et al*., 1992).

Outro fator que evidenciou a forte carga de matéria orgânica em decomposição foi a grande freqüência de larvas de poliquetas e de nemátodes nos viveiros. Destaca-se que foram observados vários estágios larvais de Nematoda, principalmente nas fazendas Cina e Papagaio, que pertenciam a *A. duodenale*. De acordo com Rey (2002) as larvas se desenvolvem em ambiente aquático, preferencialmente no período chuvoso, vivendo em temperatura ideal entre 23 e 30°C e os adultos em solo úmido em regiões que recebe esgotos domésticos. Trata-se de parasita prejudicial ao homem.

A ocorrência de formas jovens de camarão (estágio de *Mysis*), parasitada com protozoários ectoparasitas, do tipo *Vorticella* spp. foi observada na fazenda Cina, e acentuado nesta fazenda e na fazenda Papagaio pela presença de nemátodes parasitas. Estas parasitoses costumam afetar as mudas e o desenvolvimento dos organismos infectados, diminuindo a imunidade dos animais e abrindo caminho para outros tipos de infecções, como a IMN.

A densidade total do zooplâncton nas fazendas foi alta com um mínimo de 2,915 ind m^{-3}, na Vip Camarões, e o máximo de 12,706 ind m^{-3}, na fazenda Compescal. Apenas as fazendas Papagaio, MRG, Compescal e Vip Camarões mostraram densidades mais elevadas na água do ponto de captação que nos viveiros, indicando que, de forma geral, o zooplâncton está sendo consumido pelos camarões nos primeiros dias de cultivo. De uma forma global, as áreas de captação apresentaram melhores condições que a maioria dos viveiros, nos quais predominaram muitas vezes indicadores de poluição orgânica (ciliados atecados, rotíferos, larvas de poliqueta, nemátodes, dentre outros). Embora, apresentem forte decomposição orgânica, ainda ocorrem náuplios de copépodes e larvas de Bivalvia em grandes quantidades nos viveiros, mostrando a importância do fluxo marinho na renovação do ambiente na área de captação da água e melhoria da saúde ambiental, como mostrado em áreas estuarinas altamente impactadas no Nordeste do Brasil (NEUMANN-LEITÃO, MATSUMURA-TUNDISI, 1998).

Em algumas amostras obtidas na captação, principalmente nas fazendas Cina, Papagaio, Compescal e A.S. Marine, observou-se uma expressiva quantidade e diversidade de organismos zooplanctônicos, indicadores de ambientes estuarinos. A entrada excessiva destes organismos em um ambiente enriquecido como os viveiros, pode originar o crescimento acentuado de alguns organismos (rotíferos e protozoários, p. ex.), ocasionando modificações na qualidade da água, podendo reduzir o oxigênio dissolvido da água, prejudicando os organismos cultivados. Medidas preventivas como a filtração da água com rede de 150 µm podem auxiliar na redução destes organismos planctônicos e contribuir para uma maior estabilidade ambiental dos viveiros.

A abundância do zooplâncton variou de 221.77 ± 152.12 ind m^{-3}, no viveiro 1 da fazenda Cina, para 2.513,35 ± 1.603,56 ind m^{-3}, no viveiro 1 da fazenda Compescal. Com relação aos períodos de amostragem, não foi observada a formação de um padrão nas fazendas ao longo das campanhas.

A diversidade de espécies na maioria das amostras foi baixa, seguindo o mesmo padrão do fitoplâncton. Os índices mais baixos foram observados na fazenda Aquafort (1.26 bits ind^{-1}) e mais altos na fazenda Promares (1.75 bits ind^{-1}), devido à presença de poucas espécies, fato comum em águas estuarinas (TUNDISI, 1970) e em viveiros eutrofizados. A menor equitabilidade foi registrada na fazenda Aquafort (0.44), causada pela dominância de poucas espécies, principalmente ciliados atecados e náuplios de Copepoda, e o máximo foi de 0.6 na fazenda Vip Camarões, onde o ecossistema apresentou melhor qualidade da água, contudo com condições pobres.

Estudos do zooplâncton em viveiros de camarão têm mostrado que estas comunidades são complexas e apresentam rápidas variações temporais em sua estrutura (COMAN *et al*., 2003). Os principais fatores que influenciam estas mudanças, assim como para o fitoplâncton, são as variações nas fontes de alimento, predação e influências das alterações nos parâmetros físico-químicos da qualidade da água. Os resultados descritos aqui sugerem uma entrada de nutrientes a partir da decomposição do alimento fornecido aos camarões afetando a densidade e a composição da comunidade planctônica. Estes resultados podem ser um importante apoio para o entendimento dos efeitos da eutrofização na estrutura do plâncton costeiro e seus efeitos na teia alimentar marinha, uma vez que a comunidade planctônica pode ser um excelente bioindicador da qualidade da água em viveiros de camarões.

Destaca-se, ainda, que embora não se tenha encontrado uma correlação entre o zooplâncton e a enfermidade Mionecrose Infecciosa (IMN) observada nos camarões uma das possíveis causas é a grande redução da qualidade da água afetando toda biota.

Pode-se concluir pelos resultados obtidos que os viveiros estão sob estresse ambiental e parece ser razoável assumir que o excesso de fertilizantes adicionado aos viveiros somado a carga de ração recebida diariamente contribuem de forma negativa em mudanças na estrutura trófica planctônica, sendo recomendado um manejo mais adequado para que bons resultados da produção de camarões sejam alcançados.

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Anexos

Anexo A – Normas da revista Marine Pollution Bulletin.

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Anexo C – Normas da revista Research.

Aquaculture Research

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