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ÉRIKA PINHO CORREIA

EFEITOS DAS MUDANÇAS AMBIENTAIS GLOBAIS NAS ESPÉCIES-CHAVE DE COPEPODA DE UMA ÁREA ESTUARINA TROPICAL

Recife
2018

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Tese apresentada ao Programa de Pós-Graduação em Oceanografia da Universidade Federal de Pernambuco, como requisito parcial para a obtenção do título de Doutor em Oceanografia.

Área de concentração: Oceanografia

Orientador: Profª. Dra. Sigrid Neumann Leitão

Coorientador: Profº. Dr. Manuel de Jesus Flores Montes.

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Ao meu Voinho.

Saudades!

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“We need the sea:
it teaches me.”
NERUDA (2004)

RESUMO

O objetivo principal da tese é investigar os efeitos das mudanças ambientais globais sob as espécies-chave de Copepoda no sistema estuarino do Canal de Santa Cruz (Pernambuco – Brasil). Para atingir este objetivo, inicialmente foi feito um levantamento bibliográfico dos dados pretéritos (desde a década de 1970), tanto para dados ambientais como para dados bióticos, para buscar padrões e definir quais são as espécies-chave de Copepoda. A partir deste levantamento, foi possível redigir o primeiro capítulo da tese, que descreve todos os estudos sobre o zooplâncton já realizados na área de estudo. Como conclusão deste capítulo, foi possível constatar uma descontinuidade na abordagem, amostragem e nos estudos como um todo nesta área, fazendo com que o futuro desta área ainda seja um grande ponto de interrogação e, ainda, sugerir a criação de um sistema contínuo de avalição desta que é uma das áreas estuarinas mais importantes biologica e socialmente no Nordeste do Brasil. Após o levantamento, constatou-se que *Acartia lilljeborgi* e *Oithona hebes* são as espécies-chave para o sistema estuarino estudado. Foram separadas amostras (desde a década de 1970) localizadas na coleção de Zooplâncton do Museu de Oceanografia (MOUFPE) e feitas contagens e medições do tamanho corporal de organismos das duas espécies em questão. A partir disto, foram redigidos mais dois capítulos da tese, que tratam das relações de parâmetros ambientais com o tamanho corporal, densidade e produção secundária de *A. lilljeborgi* e *O. hebes*, além de alguns aspectos populacionais do gênero *Oithona*. Foi constatado que a temperatura tem influência significativa e está correlacionada negativamente com o tamanho corporal de *A. lilljeborgi*. Ainda, a abundância de *Oithona* spp. em relação ao total de Copepoda aumentou significativamente entre os anos de 1975 e 2016, o que indica uma mudança na teia trófica da área do Canal de Santa Cruz. Por fim, clorofila a, pH e oxigênio dissolvido apresentaram influência significativa sob o tamanho corporal (correlação negativa) e a produção secundária (correlação positiva) de *Oithona hebes*, enquanto a temperatura e o pH foram os principais fatores a influenciar a densidade desta espécie, estando positivamente correlacionados. A partir dos resultados destes dois capítulos, foi possível aceitar a hipótese de que as espécies-chave de Copepoda do sistema estuarino do Canal de Santa Cruz têm sofrido com as mudanças ambientais globais.

Palavras-chave: *Acartia lilljeborgi*. Copepoda. Eutrofização. Impactos antrópicos. *Oithona hebes*.

ABSTRACT

The main objective of this thesis is to investigate the effects of the global environmental changes on Copepoda key species in the Santa Cruz Channel estuarine system (Pernambuco – Brazil). To achieve this goal, initially, a bibliographic survey from former data was made (since 1970s decade), for both environmental and biotic data, to search for patterns and to define which are the Copepoda key species. From this survey, it was possible to write the first chapter of the thesis, which describes all the studies about zooplankton already made for the study area. As a conclusion from this chapter, it was possible to observe a discontinuity on the approach, sampling and on the studies as a whole, making that the future of this area is still a question mark. This chapter also suggests a creation of a continuous evaluation system of this area that is one of the most important biological and economical estuarine areas from Northeast of Brazil. After the survey, it was found that *Acartia lilljeborgi* and *Oithona hebes* are the key species from the studied estuarine system. Samples from Zooplankton Collection of the Oceanographic Museum (MOUFPE) were separated (since 1970s decade), and counting and body size measurement of the organisms from the two species in question. Since then, two more chapters were written, which deal with the relations of environmental parameters with the body size, abundance and secondary production of *A. lilljeborgi* and *O. hebes*, besides some other population aspects of *Oithona* genus. It was found that the temperature has a significant influence and is negatively correlated with the body size of *A. lilljeborgi*. In addition, the *Oithona* spp. abundance in relation to Copepoda total significantly increased between the years 1975 and 2016, which indicates a change in the trophic web in the Santa Cruz Channel. At last, chlorophyll a, pH and dissolved oxygen presented significant influence on the body size (negative correlation) and secondary production (positive correlation) of *O. hebes*, as long as temperature and pH were the main factors influencing the abundance of this species, being positively correlated. From these results, it was possible to accept the hypothesis that the key species of Copepoda in the Santa Cruz Channel estuarine system are suffering from the global environmental changes.

Keywords: Anthropogenic impacts. *Acartia lilljeborgi*. Copepoda. Eutrophication. *Oithona hebes*.

SUMÁRIO

1 INTRODUÇÃO

Atualmente, há a certeza de que as mudanças ambientais globais estão acontecendo e de que elas são aceleradas pelos seres humanos: o crescimento populacional e o aumento na demanda por recursos naturais são os principais fatores conduzindo-as (CAMILL, 2010). Dentre os desafios para os cientistas que estudam os oceanos estão a compreensão e também a predição da resposta dos organismos marinhos frente às essas mudanças (DAM, 2013). De acordo com Vitousek (1994), três das principais e mais bem documentadas causas dessas mudanças são o aumento da concentração de CO_2 na atmosfera, alterações na biogeoquímica do ciclo global do nitrogênio e as alterações em curso no uso e ocupação do solo. O autor pontua, ainda, que estas três causas somadas a outros componentes das mudanças ambientais globais são as causas primárias de transformações antecipadas no clima e das perdas de diversidade biológica que estão em curso. Aqui, abordaremos apenas as duas primeiras.

Os oceanos desempenham um papel central no clima da Terra e absorveram 93% da energia extra proveniente do efeito estufa e aproximadamente 30% do CO_2 antropogênico da atmosfera (IPCC, 2014a). O aumento nas concentrações atmosféricas dos gases do efeito estufa, principalmente o CO_2, através da queima dos combustíveis fósseis, é um fator chave levando ao aquecimento em escala global da atmosfera e do oceano (CHEW; CHONG, 2016). Dentro desta escala, o aquecimento dos oceanos é maior próximo à superfície, e os 75 m mais superficiais da coluna d'água aqueceram 0,11ºC (± 0,02ºC) por década durante o período de 1971 a 2010 (IPCC, 2014a). A média da temperatura superficial do mar do Oceano Atlântico aumentou 0,41ºC no período de 1950 e 2009 (IPCC, 2014b), e deve continuar a aumentar, em uma escala global, durante o século XXI (IPCC, 2014a).

Estudos apontam que as mudanças climáticas antropogênicas provavelmente irão alterar a fisiologia (FABRY et al., 2008; SOMERO, 2012) e modificar a distribuição espacial (PARMESAN, 2006; POLOCZANSKA et al., 2013) dos organismos marinhos devido, por exemplo, à restrição do habitat e à redução da biomassa disponível para os níveis tróficos mais elevados (JONES et al., 2014; DUERI et al., 2014). A compreensão da relação entre o clima e organismos planctônicos também ainda está em um estado inicial, grande parte devido à falta de informações nos oceanos de todo o mundo. Um grande desafio para a gestão ambiental dos sistemas marinhos é identificar indicadores ecológicos simples que capturem a complexidade inerente do ecossistema (ROMBOUTS et al., 2013). Neste contexto, Rombouts et al. (2013) sugeriram que é possível reduzir essa complexidade para formas simplificadas que vão representar os fatores-chave dos ecossistemas, onde os referidos autores alocam o zooplâncton como um grupo funcional chave para a avaliação do ambiente.

Os organismos zooplanctônicos fornecem subsídios, através de sua distribuição, morfologia, comportamento e estado fisiológico (HAURY; PIEPER, 1988) sobre os processos interagentes, uma vez que as suas comunidades são influenciadas pelas condições abióticas e bióticas do ambiente (DAY JR et al., 1989; BUSKEY, 1993). Estes organismos agem como um integrador de uma vasta gama de fatores hidrometeorológicos e mudanças na sua abundância e variações na estrutura das comunidades fazem com que atuem como indicadores de mudanças climáticas e do efeito do aquecimento global (REID; EDWARDS, 2001; BEAUGRAND, 2009). Entretanto, segundo Wernberg et al. (2012), o zooplâncton é um dos grupos de organismos com menor número de estudos sobre mudanças climáticas. Apesar da pequena quantidade de estudos, já se sabe que este grupo de organismos é um indicador mais sensível a mudanças climáticas do que variáveis ambientais por elas mesmas (TAYLOR, 2002).

As mudanças climáticas conjuntamente com os impactos antropogênicos (como a eutrofização) no ambiente marinho podem levar a outros tipos de mudanças em série na função do ecossistema (ex. LI et al., 2009; MÖLLMANN et al., 2008; SUIKKANEN et al., 2013). A eutrofização costeira é um fenômeno que teve progresso em sua investigação científica há apenas algumas décadas (CLOERN et al., 2001).

A eutrofização é um aumento na taxa de suprimento de matéria orgânica a um ecossistema, segundo definição proposta por Nixon (1995), enfatizando que a eutrofização é um processo e não um estado trófico. Vários fatores podem aumentar este suprimento de matéria orgânica aos sistemas costeiros, mas o fator mais comum é claramente o enriquecimento de nutrientes (NIXON, 1995), principalmente nitrogênio e fósforo. As atividades humanas aumentaram consideravelmente os fluxos de nutrientes para estuários e outros ecossistemas marinhos costeiros ao longo da última metade do século, aumentando a produção primária e causando uma eutrofização generalizada (NIXON, 1995; RABALAIS, 2002).

Esse enriquecimento de nutrientes gera, nos ambientes aquáticos, dois efeitos principais e que estão correlacionados. Primeiramente, ocorre a estimulação do crescimento do fitoplâncton (MCQUATTERS-GOLLOP et al., 2009), o que aumenta sua biomassa, entretanto, em muitos casos, ocorre uma substituição das microalgas maiores e mais nutritivas por outras pequenas, pouco nutritivas, e até mesmo tóxicas (HUTCHINS et al., 2007). Em seguida, ocorre um aumento na matéria orgânica particulada suspensa nas áreas estuarinas e costeiras, o que pode induzir a maior produtividade de bactérias heterotróficas (SARMENTO et al., 2010), reduzindo a quantidade de oxigênio dissolvido na água, induzindo a hipóxia (CHEW; CHONG, 2016).

Marcus (1994) fez uma revisão sobre os impactos da eutrofização sob os Copepoda das zonas costeiras e constatou que a eutrofização pode afetar estes organismos através de vários mecanismos diferentes. Dentre estes mecanismos, pode-se citar: melhores condições de alimentação para os Copepoda (BAUTISTA; HARRIS, 1992; NEJSTGAARD et al., 1995; HANSEN et al., 2000) e consequente aumento na biomassa (UYE et al., 2000); mudança na proporção dos nutrientes que pode alterar a diversidade e sucessão das espécies zooplanctônicas (PARK; MARSHALL, 2000); substituição de espécies maiores por espécies menores de Copepoda (UYE, 1994); alterações no comportamento de migração para evitar hipóxia causada pela eutrofização (STALDER; MARCUS, 1997; DECKER et al., 2003; entre outros).

Em uma escala global, os ecossistemas costeiros são fortemente impactados pelas atividades humanas. E isto ocorre porque o desenvolvimento das populações humanas é historicamente concentrado em áreas costeiras, causando alterações profundas nestes ambientes (VAN ANDEL, 1981). Estes ambientes estuarinos e costeiros estão entre os sistemas aquáticos mais importantes na Terra, em termos de relevância ecológica e econômica (KENNISH, 1997). Ainda, estão sujeitos a uma série de impactos antrópicos diretos e indiretos, além dos efeitos de variabilidade natural do ambiente marinho relacionado com forçantes hidroclimáticas (VIITASALO et al., 1995; BEAUGRAND et al., 2000; REID; BEAUGRAND, 2002), como as mudanças ambientais globais.

As alterações de ambientes costeiros e estuarinos, assim como de outros ecossistemas marinhos, tem levado a uma preocupação mundial com ameaças ambientais, desenvolvimento sustentável e mudanças climáticas. A partir disso, esforços para o monitoramento assim como para a avaliação do estado e das tendências da condição ambiental tem aumentado (JACKSON et al., 2000).

1.1 ESTRUTURA E OBJETIVOS DA TESE

O presente estudo, que fez parte de projetos desenvolvidos ao longo das últimas décadas no sistema estuarino do Canal de Santa Cruz e se propõe a testar a hipótese de que as espécies-chave de Copepoda no sistema estuarino do Canal de Santa Cruz tem sofrido com os efeitos (mudanças nos valores de tamanho corporal, densidade, composição, biomassa e produção) das mudanças ambientais globais.

Para testar essa hipótese, este estudo visou investigar os efeitos das mudanças ambientais globais nas espécies-chave de Copepoda do sistema estuarino do Canal de Santa Cruz (Itamaracá – Brasil) ao longo de uma série temporal de 35 anos. Ainda, este estudo teve como objetivos específicos: (1) caracterizar a comunidade zooplanctônica do sistema estuarino do Canal de Santa Cruz ao longo de 35 anos; (2) definição das espécies-chave de Copepoda na área estudada a partir da década de 1970; (3) reanalisar amostras pretéritas para obtenção dos valores dos parâmetros biológicos (tamanho corporal, densidade, biomassa e produção); (4) relacionar os parâmetros ambientais (temperatura, salinidade, oxigênio dissolvido, pH, transparência e clorofila-a) com parâmetros biológicos (tamanho corporal, densidade, biomassa e produção) ao longo de 35 anos no sistema estuarino do Canal de Santa Cruz.

Esta tese é composta por três capítulos:

Capítulo I: “Thirty-five years of zooplankton studies in a tropical estuarine ecosystem” – atendendo aos objetivos específicos 1 e 2.

Capítulo II: “Copepod community responses to temperature, mainly *Acartia (Odontocartia) lilljeborgi* Giesbrechti, 1889, in a tropical estuarine system” – atendendo aos objetivos específicos 3 e 4.

Capítulo III: “Effects of environmental parameters on body size, production, and abundance of *Oithona hebes* Giesbrechti, 1891 in a tropical estuary” – atendendo aos objetivos específicos 3 e 4.

2 MÉTODO

2.1 ÁREA DE ESTUDO

A Ilha de Itamaracá está localizada no estado de Pernambuco, cerca de 50 km ao Norte da cidade do Recife, entre as coordenadas 7º 34’00” S e 7º 55’16” S de latitude e 34º48’48” W e 34º52’24” W de longitude. O clima da área é classificado como tropical Am de acordo com a classificação de Köppen e Geiger, com dois períodos anuais: um seco (de setembro a fevereiro, com precipitação < 200 mm) e um chuvoso (de março a agosto, com precipitação > 200 mm), sendo a média de precipitação anual de 2085 mm. A temperatura média ao longo do ano é de 25,4 ºC (https://pt.climate-data.org/location/42658/).

De acordo com Kempf (1967), a Ilha de Itamaracá está simplesmente isolada da linha de costa por um braço de mar que penetra no continente. Esse braço de mar, conhecido como Canal de Santa Cruz, tem 22 km de extensão e largura que varia entre 0,6 e 1,5 km. Toda a área tem baixa profundidade, com média de 4-5 m em todo Canal, em maré baixa, e geralmente abaixo dos 2 m.

Este canal se comunica com o mar pelo Norte através da Barra de Catuama e pelo Sul através da Barra Orange. Ainda, o canal recebe a influência continental de vários rios que desaguam nele. Na porção Norte os rios Catuama, Carrapicho, Botafogo e Congo contribuem, enquanto na porção Sul são os rios Igarassu e Paripe. Ao todo, sua bacia hidrográfica cobre uma área de aproximadamente 750 km² (MACÊDO, 1974).

A plataforma continental adjacente à Ilha de Itamaracá é rasa, não ultrapassa 32 km de largura, com sua porção interna sendo caracterizada pela presença de recifes, com 2 metros de profundidade, aproximadamente. O ecossistema manguezal ao longo do Canal de Santa Cruz ocorre em quase toda sua extensão com *Rhizophora mangle* L. correspondendo a aproximadamente 82% da cobertura vegetal da área (RAMOS-PORTO, 1980).

2.2 DESCRIÇÃO DOS MÉTODOS

2.2.1 Métodos do Capítulo I

Para obter os dados utilizados no Capítulo I, uma pesquisa complete foi desenvolvida através da análise de publicações que tratavam sobre o zooplâncton do Canal de Santa Cruz, a partir da década de 1970, utilizando principalmente as seguintes palavras-chave: plâncton, zooplâncton, Copepoda, Itamaracá, Canal de Santa Cruz, rio Botafogo, rio Igarassu, rio Carrapicho, rio Catuama, larva de Crustacea, larva de peixe. Para esse propósito, várias fontes de dados foram utilizados: os sites Google Scholar (http://www.scholar.google.com.br), Scielo (scielo.org) e Web of Knowledge (http://www.wokinfo.com/), dissertações e teses (http://www.bdtd.ibict.br/; http://www.capes.gov.br/servicos/banco-de-teses; http://www.teses.usp.br/; http://www. dominiopublico.gov.br/pesquisa/pesquisaperiodico), assim como anais de conferências e livros e capítulos de livros publicados.

2.2.2 Métodos do Capítulo II

Para o capítulo II, foi feita uma pesquisa nas amostras de zooplâncton do sistema estuarino do Canal de Santa Cruz armazenadas no Museu de Oceanografia da UFPE (MOUFPE) coletadas a partir da década de 1970. Após isso, foram selecionadas amostras coletadas com rede de malha de 64 µm de abertura dos anos 1975 (outubro e novembro), 1995 (março), 1996 (dezembro) e 2007 (março, novembro e dezembro). Três amostras do período seco de cada ano foram analizadas, a fim de excluir a influência da sazonalidade.

A espécie *Acartia lilljeborgi* e o gênero *Oithona* foram identificados e contados, enquanto medições foram feitas para *A. lilljeborgi*. Novas amostras com a mesma malha de abertura foram coletadas em 2016 (janeiro) no Canal de Santa Cruz. Foi utilizada a mesma metodologia de coleta que a utilizada nas amostras mais antigas: arrastos subsuperficiais de 3 minutos de duração e fixadas com uma solução de formol neutralizado (4%).

No laboratório, as amostras foram diluídas para valores entre 25 e 2200 mL e, em seguida, uma alíquota de 1 mL de cada amostra foi analisada. O número total de Copepoda, tanto juvenis como adultos, do gênero *Oithona* e de *A. lilljeborgi* foram contados em cada alíquota. Após isso, foram capturadas 20 fêmeas adultas de *A. lilljeborgi* para medição.

Os dados de temperatura utilizados neste capítulo são originados dos trabalhos Ezkinazi-Leça et al. (1984), Porto-Neto et al., (1999), Schwamborn et al., (2001) e Nascimento Filho (2014). Ainda, os dados de temperatura das coletas de campo em janeiro de 2016 também foram utilizados. Todos os valores de temperatura foram obtidos dos mesmos meses das amostras analisadas.

As abundâncias relativas do gênero *Oithona* e de *A. lilljeborgi* em relação ao total de Copepoda foram calculadas através de uma divisão simples entre o número total de *Oithona*/indivíduos de *A.lilljeborgi* pelo número total de Copepoda (P% = NOithona ou Acartia/NCopepoda x 100). Para os testes estatísticos, os dados tiveram a normalidade testada ursando o teste de Shapiro-Wilk. Os dados paramétricos foram comparados utilizando uma análise de variância (ANOVA, one-way); enquanto dados não paramétricos foi utilizada a

ANOVA de Kruskal-Wallis. Para verificar a existência de relações entre a temperatura e o tamanho corporal, a abundância e a produção secundária, regressões simples e a correlação de Pearson foram calculadas. Todas as análises foram feitas utilizaram o programa SigmaPlot12 e valores de $p > 0,05$ foram tomados como significativos.

2.2.3 Métodos do Capítulo III

Para o capítulo III, as amostragens de plâncton foram feitas de janeiro a dezembro de 1975 e de março de 2007 a fevereiro de 2008, durante a maré alta, em três estações ao longo do estuário do rio Botafogo. A metodologia utilizada nos dois períodos amostrais foi a mesma: arrastos subsuperficiais com 3 minutos de duração com uma rede de plâncton de 64 µm de abertura de malha. As amostras foram fixadas com 4% de formaldedído neutralizado com tetraborato de sódio (NEWELL; NEWELL, 1963).

Os dados hidrológicos foram obtidos na subsuperfície, com as mesmas metodologias nos dois períodos amostrais, ao mesmo tempo em que as amostras do zooplâncton eram coletadas: a temperatura (ºC) foi obtida com um termômetro digital; a transparência (m) com um disco de Secchi; a salinidade através do método de Mohr-Knudsen (STRICKLAND; PARSONS, 1965). O pH foi obtido com um pHmêtro Beckman Zeromatic II; o oxigênio dissolvido ($mL.L^{-1}$) através dos métodos de Winkler (STRICKLAND; PARSONS, 1972) e UNESCO (1973); e, por fim, a clorofila-a ($mg.m^{-3}$) através de um espectrofotômetro Micronal B280 (PARSONS; STRICKLAND, 1963).

No laboratório, três alíquotas de 1 mL de cada amostra foram analisadas e todas as *Oithona hebes* foram contadas. O prossoma dos 30 primeiros indivíduos adultos de *Oithona hebes* de cada amostra foram medidos para calcular o peso seco (PS) (µm) usando a equação linear $PS = 3,405 \times 10^{-10} CP^{3,463}$, onde CP é o comprimento do prossoma (ARA, 2001). Então, o PS foi convertido para carbono (C) considerando que $C = 0,40 \times PS$ (POSTEL et al., 2000). Os valores de biomassa (B, $mg\ C\ m^{-3}$) foram calculados a partir de $B = PS \times D \times 10^{-3}$, considerando o PS em carbono (C), e D = densidade ($ind\ m^{-3}$).

A produção de *Oithona hebes* ($mg\ C\ m^{-3}\ day^{-1}$) foi calculada através do produto entre a taxa de crescimento instantâneo e a biomassa. Para estimar a taxa de crescimento instantâneo (g) foi utilizado o modelo de Hirst e Bunker (2003). Neste modelo, a temperatura da água (T), o peso seco em carbono (C) e a clorofila-a (Chl) são considerados. Adultos e juvenis são considerados juntos, na equação: *H-B*: $Log10\ g = 0.0186\ [T] - 0.288\ [log10PS] + 0.417\ [log10Chl] - 1.209$.

Com relação aos testes estatísticos utilizados neste capítulo, foi seguida a mesma rotina realizada para obtenção dos resultados do capítulo II, também com os valores de $p < 0,05$ tomados como significativos.

3 RESULTADOS

3.1 THIRTY-FIVE YEARS OF ZOOPLANKTON STUDIES IN A TROPICAL ESTUARINE ECOSYSTEM

INTRODUCTION

Estuarine and coastal environments are among the most important aquatic systems on earth, in terms of ecologic and economic relevance (KENNISH, 1997). The estuaries provide a variety of ecosystemic services and social benefits due to its connections with continent, freshwater and marine surroundings systems (O'HIGGINS et al. 2010; BARBIER et al. 2011). These environments "face" quick and strong physicochemical changes, in time and space scales, preventing the establishment of a complex estuarine food web. This, however, allows the system to be very productive and dynamically stable in terms of energy flux and consumers population dynamics (MOORE et al. 2004; LOBRY et al. 2008; SELLESLAGH et al. 2012).

Due to this high productivity, besides the refuge they provide to organisms, the estuaries with its mangroves are important feeding areas, sustaining an abundant population of marine and estuarine species, such as various initial phases of the life cycle of many fishes and invertebrates, which finish their life cycle at the sea (MCLUSKY; ELLIOTT, 2004).

In the aquatic environments, the zooplankton behaves like one of the most important groups on the food web and performs a key role. This group is responsible for energy transfer between the phyto and bacterioplankton to higher trophic levels (BUSKEY, 1993; LEVINTON, 1995); concerning estuaries, these higher trophic levels include many fishes and crustaceans of commercial interests (DAY JR. et al. 1989). They present bioindicators of water quality, providing subsidies about the main processes in these water bodies, as their communities are directly influenced by abiotic and biotic conditions (DAY JR. et al. 1989, BUSKEY, 1993).

The estuarine system of the Santa Cruz Channel (Pernambuco - Brasil) is considered as one of the most productive in the Northeast of Brazil [with medians greater than 120 t of monthly fisheries landings (NASCIMENTO et al., 2013)], a huge biodiversity and productivity, representing an important environmental and socioeconomic system (MACEDO et al. 2000).

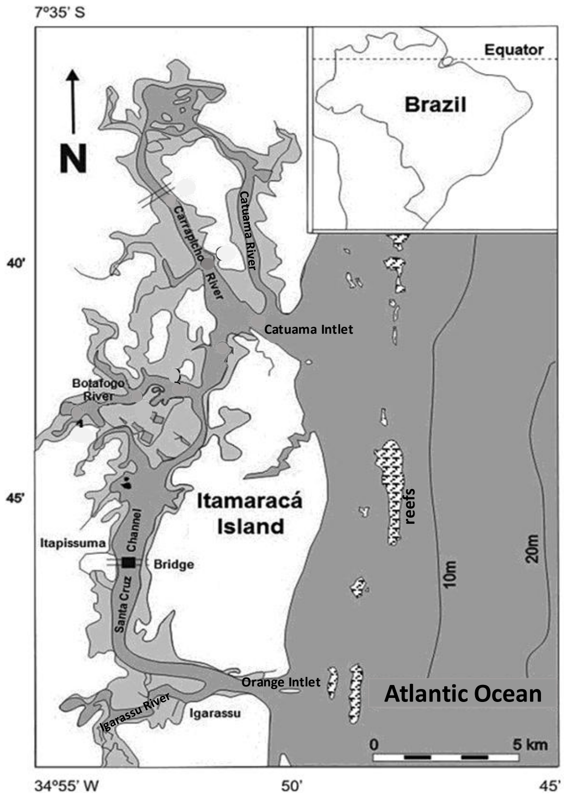
The present study consists of a survey of all scientific material already produced about the zooplankton of the estuarine ecosystem of the Santa Cruz Channel (Pernambuco - Brazil). In this way, this study has the objective to synthesize the knowledge about the biodiversity, composition, distribution, abundance and other biological parameters of the zooplankton in this ecosystem and to propose solutions to improve the sustainable management of this area.

DEVELOPMENT

Study area

The Itamaracá Island is located in the Pernambuco state, about 50 km north from the city of Recife, between 7º 34'00" S and 7º 55'16" S latitude and 34º48'48" W and 34º52'24" W longitude (Figure 1).

Figure 1 - Santa Cruz Channel estuarine system (Pernambuco, Brazil).



Fonte: A autora.

The climate is classified as tropical Am according to Köppen and Geiger's classification, with two annual periods, a dry (September to February, rainfall <200 mm) and a rainy (March to August, rainfall >200 mm) with average annual rainfall of 2085 mm. The average annual temperature is 25.4°C (https://pt.climate-data.org/location/42658/).

According to Kempf (1967), the Itamaracá Island is not far away from the coastal line, but simply isolated by an ocean inlet that penetrates the continent. This ocean inlet, known as Santa Cruz Channel, has 22 km of extension and variable width from 0.6 to 1.5 km. The entire area is shallow, with average depth within the Channel around 4-5 m, in the low tide, and often below 2 m.

The channel communicates with the sea to the north, by Catuama Intlet, and to the south, by Orange Intlet. Also, it receives the continental influence through several rivers, mainly, in the north portion, the Catuama, Carrapicho, Botafogo and Congo rivers, and in the south portion, the Igarassu and Paripe rivers. In all, the watershed covers about 750 km² (MACÊDO, 1974).

The adjacent continental shelf to the Itamaracá Island is narrow, not surpassing 20 miles' width, with its internal portion being characterized by the presence of reefs, with 2 m depth, approximately. These reefs have a coralline formation (corals and fouling calcareous algae), established over a totally covered sandstone basis, presenting a dense algae covering composed mainly of Chlorophyceae and Phaeophyceae. Near to the coast, the substrate is composed of fluvial quartz sand facies and is densely populated by the seagrass *Halodule wrightii* (MAGALHÃES et al. 1997).

The mangrove ecosystem along the Santa Cruz Channel occur in almost its whole extension and has a vegetal covering of *Rhizophora mangle* L., representing 82% of covering, followed by *Laguncularia racemosa* Gaertn, *Avicennia schaueriana* Staf and Leechman with 9% and, a smaller number of individuals of *Avicennia germinans* (L.) Sterarn and *Conocarpus erecta* L. (RAMOS-PORTO, 1980).

Data collection

To obtain the data utilized on this study, it was carried out a complete survey through an analysis of publications about the zooplankton from the Santa Cruz Channel (Itamaracá – Permabuco), from the 1970 decade, using the mainly, the following key words: Plankton, Zooplankton, Copepoda, Itamaracá, Santa Cruz Channel, Botafogo River, Igarassu River, Carrapicho and Catuama rivers, Crustacean and Fish Larvae.

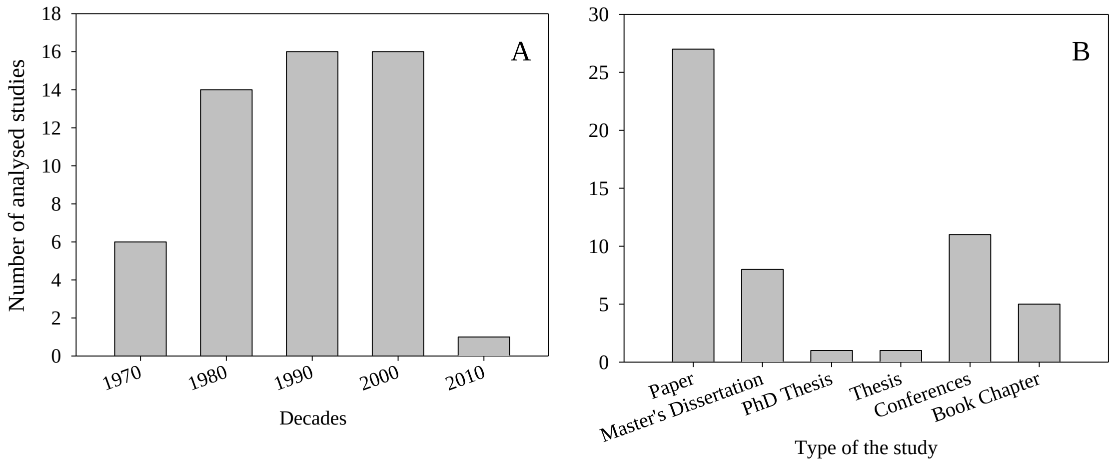
For this purpose, several data sources have been used. The data bank of Google Scholar (http://www.scholar.google.com.br), Scielo (scielo.org) and Web of Knowledge (http://www.wokinfo.com/) websites, dissertations and thesis (http://www.bdtd.ibict.br/; http://www.capes.gov.br/servicos/banco-de-teses; http://www.teses.usp.br/; http://www.

dominiopublico.gov.br/pesquisa/pesquisaperiodico), along with conferences reports and published book chapters.

Initial considerations

As from the bibliographic survey carried out until December/2017, 52 scientific studies were evaluated, being: 6 in the 1970 decade, 14 in the 1980 decade, 16 in the 1990 decade, 15 in the 2000 decade and only 1 in the 2010 decade (Figure 2A). In relation to the types of existent studies: 26 are full papers, 8 dissertations, 1 thesis, 1 professorship thesis, 11 conference reports and 5 book chapters (Figure 2B). The summary from the results of all these scientific studies will be presented here.

Figure 2 - A) Number of analyzed studies of zooplankton on Santa Cruz Channel estuarine system; B) Number of analyzed studies of zooplankton on Santa Cruz Channel estuarine system in relation to the type of the study.



Fonte: A autora.

This study is divided into four sections. The first one is about the initial and exploratory studies about the zooplankton of the Santa Cruz Channel estuarine system from the 1970 and 1980 decades; the first discoveries, evaluations and quantifications of which organisms inhabited the area, as well as studies about zooplanktonic organisms in cultureponds located in the area. The second section addresses exclusively about the 1990 decade, describing the large turning point in the study of these organisms in the Santa Cruz Channel, with the consolidation of important international partnerships and the increasing complexity of the studies and projects performed.

The third section refers to the 2000 decade and the creation and consolidation of an important project about the flux and dynamics of zooplanktonic organisms in the Santa Cruz Channel in the beginning of the decade; another large project focusing on zooplankton as indicators of environmental quality of this area was also made within this decade. The fourth and last section emphasizes the last project carried out in the Santa Cruz Channel estuarine system and the decline of the number of studies in the area during the following decade.

The principle: 1970's and 1980's decades, the exploratory studies and the natural ponds

The estuarine ecosystem of Itamaracá, where the Santa Cruz Channel is located, has been massively studied since 1970 decade, from the initiative of the Department of Oceanography of the Federal University of Pernambuco, supported by SUDENE (Superintendence of Northeast Development), which aimed the development of estuarine fishculture, as a means of stimulating the economic growth of the area. These studies were of substantial importance to the characterization of the whole ecosystem and approached the geology, physics, chemistry and biology.

For the zooplankton, objective of this work, the pioneer study was performed in the estuary of the Igarassu river, between May of 1973 and April of 1974, when samples were collected with a plankton net with 65 µm of mesh size in 4 fixed stations. This was the first study about the composition and distribution of zooplankton in this area. It was not observed any defined seasonal cycle, with emphasis being placed on the Copepoda species *Acartia lilljeborgi*, as well as *Centropages* and *Oithona*, at the time still identified only at gender level. In the meroplankton were predominant the Mollusca larvae of *Mytella charruana*, *M. guyanensis* and *Crassostrea rhizophorae* (PARANAGUÁ and NASCIMENTO, 1973; PARANAGUÁ et al. 1979). These authors highlighted the possibility of an intimate relation between the cycle of phytoplankton and, particularly, the Copepoda in this area. As part of the sampling performed in the area, Nascimento (1977) firstly reported the occurrence of *Euterpina acutifrons* in the Santa Cruz Channel.

The second estuary of the area to be studied in terms of composition and general distribution of the zooplankton was the Botafogo River, where it was used two plankton nets with 65 and 120 µm mesh sizes (NASCIMENTO, 1980; NASCIMENTO; PARANAGUÁ, 1981).

Based on this material, Nascimento (1981) studied in detail the Copepoda group, having identified 9 species, among which *Acartia lilljeborgi* was the most relevant due its high frequency of occurrence and abundance. The same author concluded that the distribution of species was associated primarily with the estuary salinity, with a richer fauna in areas with higher salinity.

Paranaguá and Nascimento-Vieira (1984), also utilizing the same material, studied the whole zooplankton of the Botafogo river estuary. The authors observed the mesh selectivity, reporting that the higher concentration of planktonic organisms was found in the 65 µm mesh size, fact also observed by Paranaguá and Gusmão (1980), who utilized the same sampling methodology. They highlighted that the Copepoda excelled quantitatively among the other 20 zooplanktonic taxa identified in the study. In addition, they discarded an annual cycle of the zooplankton in the studied area, such as done previously by Paranaguá et al. (1979).

The creation of the Fishculture Basis of Itamaracá - PE, in agreement with the government of Pernambuco State and supported by SUDENE, allowed, from 1976, to perform a series of researches about zooplankton in estuarine natural, rationed and fertilized ponds. The first results of these researches revealed a similar composition, in all ponds, although the fertilized presented higher densities of the Rotifera *Brachionus plicatilis* (PARANAGUÁ; KOENING, 1977; 1980, SANTANA, 1978a; 1978b; PARANAGUÁ; NEUMANN-LEITÃO, 1980; 1981; PARANAGUÁ et al. 1986). Afterwards, a synthesis of the researches in these ponds, showed that predominated the Tintinidea *Favella ehrenbergii*, the Rotifera *Brachionus plicatilis* and the Copepoda *Acartia lilljeborgi, Oithona ovalis* (currently *Oithona hebes*) and *Oithona oligohalina* (currently *Oithona oswaldocruzi*), in addition to meroplanktonic larvae (PARANAGUÁ et al. 1982; NEUMANN-LEITÃO et al. 1984). Researches about zooplankton sampling methodology in ponds ended this stage, having tested plankton nets with 65, 95 and 120 µm mesh size, verifying this selectivity, being the smaller one the most effective in density and diversity (PARANAGUÁ et al. 1981).

All studies performed in the estuarine region of Itamaracá, focusing technological perspectives in fishculture were synthesized in terms of hydrology and plankton, concluding that the whole area presents eutrophic conditions, due to the continuous input of nutrients and consequent increment of planktonic organisms, specially Bacillariophyceae, Phytoflagellata and Copepoda, which in turn serve as food to the Pisces, Crustacea and Mollusca populations (PARANAGUÁ, 1982; PARANAGUÁ; ESKINAZI-LEÇA, 1985). During this time, Por and Almeida Prado-Por (1982) characterized a polyhaline mangrove at the margins of the Santa Cruz Channel, having identified for the zooplankton the species *Euterpina acutifrons* as the most abundant, followed by *Paracalanus crassirostris* (currently *Parvocalanus crassirostris*), *Oithona ovalis* (currently *Oithona hebes*) and *Acartia lilljeborgi*.

The 1990's decade: The boom on the projects, big partnerships and the first book

Since the 1990 decade, the estuarine ecosystem area of the Santa Cruz Channel was under many projects and studies, making it to become one of the most well studied estuarine area of Brazil.

Between 1993 and 1996, it was implemented a cooperation project in oceanography between Brazil (Oceanography Department of Federal University of Pernambuco - UFPE, in Recife) and Germany (Zentrum für Marine Tropennökologie – ZMT, in Bremen). For this project, it was performed a series of samplings over the Santa Cruz Channel and in the Orange and Catuama inlets. As a result of these researches, many scientific papers, monographs, dissertations and thesis were produced.

As from the first samplings performed in this period, Ekau et al. (2001) studied the distribution of fish larvae based on 187 samples, coming from 9 stations sampled between November 1993 and May 1994, of which 50 samples were used in taxonomic composition. Theses authors observed that in the dry and rainy periods, the larvae abundance was low inside the Santa Cruz Channel. The Engraulidae larvae and different types of Gobiidae were the most dominant in the channel, reaching these two families almost 76% of the whole ichthyoplankton. Only five families were represented exclusively by larvae: Achiriidae, Cottidae, Terapontidae, Exocoetidae and Ephippidae. These authors concluded that the estuarine ecosystem of the Santa Cruz Channel is an important nursery area for various fishes.

In the year of 1994, Porto Neto et al. (1999) assessed the nictemeral and seasonal variations of the zooplankton of the Santa Cruz Channel, in three fixed stations (Orange Inlet, Catuama Inlet and Itapissuma bridge), during the dry and rainy seasons totaling 48 samples. It was used a plankton net with 65 µm of mesh size, in sub-surface hauls. The zooplankton was represented by 55 taxa (9 Phylum, 12 Classes and 26 Genders). Copepoda (mainly *Oithona hebes*, *Oithona nana*, *Oithona oswaldocruzi*, *Parvocalanus crassirostris* and *Euterpina acutifrons*) was the most abundant and diverse. Others important taxa by phylogenetic order were Tintinnina (*Favella ehrenbergii*), Foraminifera (*Cymbaloporetta atlanticus*), Cirripedia (*Balanus* sp. nauplius), Epicaridae (larvae), Polychaeta (larvae), and Larvacea (*Oikopleura dioica*). The authors concluded that the zooplankton in the Santa Cruz Channel presented wide quantitative variations, although no daily or seasonal cycles were observed, however higher densities occurring in the rainy season.

Studies of samples from 1994 were carried out by Costa et al. (2013) that focalized the protozooplankton collected in the Orange Inlet, in the south of the Santa Cruz Channel. Samplings were performed with a 65 µm mesh size net trough sub-surface horizontal hauls, in May (rainy) and December (dry) seasons in 1994, in three points over 24 hours, with intervals of three hours between samplings. The authors identified a total of 20 taxa, being the most important the Tintinnina *Leprotintinnus norqdvisti* and *Favella ehrenbergii*, and the Foraminifera *Quinqueloculina* spp. The authors concluded that the seasonality was a very important factor to the protozooplankton, with different groups of organisms dominating each season. The Tintinnina dominated during the dry, while the Foraminifera during the rainy period.

A large spatial variability in the structure of larvae community of Crustacea Decapoda in the Santa Cruz Channel was shown through the researches performed by Torbohm-Albrecht (1995); while, a quantitative approach was employed by Wehrenberg (1996), which performed samplings of plankton during 24 hours in the the Santa Cruz Channel inlets. This study showed that many taxa of Crustacea Decapoda (Brachyura and Caridae zoeas, as well as adults of *Lucifer* sp.) were exported quantitatively from the Santa Cruz Channel to the coast.

The dynamics of plankton was studied in 1994-95, to evaluate the dynamics between the estuarine and coastal environments. The sampling was done in the North and South inlets of the Santa Cruz Channel in July and December 1994, and in two perpendicular profiles to the coast direction, in February and March 1995. It was used a bongo net with four plankton nets (64, 120, 300 and 500 µm mesh size). As a result, it was identified 70 microzooplankton and 49 macrozooplankton taxa in the inlets of the Santa Cruz Channel, while 98 microzooplankton and 86 macrozooplankton taxa were identified to the shelf. The study concluded that part of the nutrients and of the organisms were exported from the estuarine ecosystem of Itamaracá to the adjacent shelf during low tide, which confirmed the mangrove important role as energy and organisms source to estuarine and marine trophic webs (SILVA et al. 2000; NEUMANN-LEITÃO et al. 2001).

Schwamborn et al. (1999) performed in 1995 studies about the contribution of Decapoda larvae exported from the estuarine system of Itamaracá to the adjacent coastal area. From their results, it was verified that the Copepoda *Acartia lilljeborgi* and the first stage of Brachyura zoea (*Uca* spp., *Ucides cordatus*, Grapsidae, and an indefinite type of zoea called

“A”) dominated the zooplankton in the area. It was reported that about 80% of the zoea that occurred in the adjacent coastal area derived from the estuarine population. The authors confirmed the mangrove importance as a source of food to the marine trophic webs. Also in 1995, the authors Schwamborn and Silva (1996) performed tests in two zooplankton communities (one coastal and one estuarine) to hypoosmotic stress, through 12 simultaneous culture experiments with different salinities. At the end of the experiment, they concluded that the estuarine community is more resistant due to the hydrographical separation of the area.

The distribution and dispersion of zooplankton, with emphasis on Decapoda larvae was investigated in the estuarine system of Itamaracá, through quantitative plankton samplings (300 µm of mesh size) during diurnal low tides, from February 1995 to May 1996. It was registered 49 zooplankton taxa, including 29 Decapoda. The most abundant were Copepoda, Brachyura zoeas, Cirripedia nauplius, adults of *Lucifer faxoni*, Chaetognatha, Appendicularia, fish eggs, Gastropoda and Upogebiidae zoeas.

The Brachyura zoeas examined belonged to the families Ocypodidae, Grapsidae, Xanthidae and Leucosiidae. *Ucides cordatus* and *Uca* spp. larvae were found only in the estuarine area, indicating that no exportation to the continental shelf. Xanthidae and Grapsidae zoeas were found in the estuarine plumes and in the shelf, although with inferior number. The grouping analysis and MDS (multidimensional scale) indicated the existence of a relatively homogenous community, however presenting a high variability of data, probably resultant from the macrozooplankton aggregation in areas of convergence (SCHWAMBORN, 1997; SCHWAMBORN et al. 2001).

Concluding the cooperation project with the ZMT – Bremen (Germany), it was performed a study to evaluate the macrozooplankton in small time scale and spatial variability in three stations with three hour intervals, during 24 hours, in July (rainy season) and December/1996 (dry season). A plankton net with 300 µm of mesh size was horizontally hauled at sub-surface for 3 minutes. It was identified 65 taxa and Copepoda constituted the most common representing 58% of the total zooplankton. Gastropoda veligers, Cirripedia larvae, Larvacea (*Oikopleura dioica*) and Brachyura zoea were abundant in some tides, mainly at night. The average density varied from 23 ind.m^{-3} to 5.201 ind.m^{-3}. The rainy season presented higher abundance. It was not observed a zooplankton cycle. Instead, there was a large stochastic variation between the samples (SILVA et al. 2000; 2003).

Silva et al. (2003) registered the first occurrence of the Copepoda *Temora turbinata* for the Estuarine System of the Santa Cruz Channel. This species was previously registered to Brazil by Araújo and Montú (1993) in the estuary of the Vasa-Barris River, also cited by Eskinazi-Sant'Anna and Björnberg (1995) to São Paulo, Espírito Santo and Rio Grande do Sul coasts. Muxagata and Gloeden (1995) mentioned its occurrence in the estuary of Patos Lagoon, Rio Grande do Sul. This species is well established in the Santa Cruz Channel, as observed by Santos et al. (2009) and Neumann-Leitão et al. (2010).

In 1997, a new cooperation project "Participative Environmental Management: Application to the case of the mangroves of Santa Cruz Channel", was implanted by three institutions (Federal Rural University of Pernambuco - UFRPE, Federal University of Pernambuco - UFPE, Joaquim Nabuco Foundation of Social Research – FUNDAJ), supported by the Programa de Apoio ao Desenvolvimento Científico e Tecnológico (PADCT - Ciamb/FINEP). The main objective of this project was to obtain a reference document, based on sustainability and capable to generate actions of the inhabitants in the rational use of their natural resources. The expectation was to complement the researches initiated in the area, characterizing upon many aspects the Estuarine Complex of Itamaracá. This project involved a joint management seeking the sustainable development and resulted in the publication of a book (BARROS et al. 2000).

Within this book, entitled "Gerenciamento Participativo de Estuários e Manguezais", Paranaguá et al. (2000) reported a synthesis of the main results of the researches performed in the Santa Cruz Channel until then, being the first chapter of book entirely dedicated to the zooplankton in this area. Still within the same book, Neumann-Leitão and Schwamborn (2000) described the trophic interactions of this local, revealing that exists a strong trophic interaction between benthos, nekton and the plankton, intense dynamics of the tides and large number of benthonic and nektonic with planktonic larvae phases, plankton organisms with resistance spores in the benthos and large contribution of the mangrove as organic material particulate and dissolved in suspension.

Ending the 1990 decade, Neumann-Leitão et al. (2005) studied the microzooplankton of the Igarassu river estuary in order to serve as tool to measure the quality of the estuarine system of the Santa Cruz Channel and provide subsidies to a best monitoring of the area. The samplings were made in the period between April and August 1999 in three fixed points, utilizing a plankton net with 65 µm of mesh size, horizontally trawled to the surface for three minutes always in daytime period. There were identified 38 taxa, highlighting the Copepoda, which also dominate in the holoplankton, being the main representatives of this group the species *Parvocalanus crassirostris, Acartia lilljeborgi* e *Oithona oswaldocruzii*. Still, meroplanktonic larvae were emphasized, mainly the Bivalvia, Gastropoda and Polychaeta ones. The authors concluded that the area is eutrophic and characterized by an estuarine microzooplanktonic community of marine origin, with occasional benthos representatives.

The 2000s decade: Independent studies, zooplankton transportation and the 'Millennium Project'

Starting the 2000 decade, Medeiros et al. (2001) published a book chapter with a synthesis of the main results of researches performed in the estuarine sustem of Itamaracá until then. The authors highlighted Copepoda (27 species) and Tintinnina (15 species) being the holoplanktonic euryhaline marine species dominant in the microzooplankton, with the abundance of this group tending to decrease in the direction of the oligotrophic waters of the shelf; Still, that the macrozooplankton (49 taxa) it is characterized by the dominance of Copepoda, Brachyura zoea (Decapoda), followed by *Lucifer* sp., Chaetognata, Larvacea, fish eggs, Gastropoda and Upogebidae zoea. They concluded that the productivity of plankton as a whole declines from the estuary to the open ocean direction.

Silva (2002) performed the first study developed in the 2000 decade by evaluating the Brachyura larvae (Crustacea, Decapoda) in the South mouth of the Santa Cruz Channel, observing the influence of tidal and lunar cycles over the distribution, productivity and dynamics of these organisms. The samplings initiated during 48 hours (March 10th and 11th, 2001) and continued bi-weekly until April 7th, 2001, completing a lunar cycle, utilizing plankton net with 300 µm of mesh size. There were identified *Uca* spp., *Ucides cordatus*, *Menippe nodifrons*, *Panopeus* sp.; Pinnotheridae morfotipo A and Pinnotheridae morfotipo B. With regard to density, there were highlighted *Uca* spp. e *Ucides cordatus*. The stage zoea I highlighted quantitatively, while stages II, III and IV were less abundant. Still, it was registered that these Brachyura larvae liberation in the environment occurs right after the full moon night and of new moon during the ebb tide.

A large project emerged in 2001, entitled "The Effect of Estuarine Convergence Zones over the Dynamic Flux of Plankton, Seston and Nutrients in the Santa Cruz Channel, Pernambuco, Brazil". This project aimed to consolidate the knowledge of dynamic processes involved in the exportation and importation of matter and organisms in tropical estuaries. Also aimed to define the mechanisms of transport of Decapoda larvae and settlement in small space-time scale, and their relation with tidal currents, convergence zone formation, and physicochemical variables (salinity, temperature, nutrients and oxygen).

Initiating the studies in this project, Melo Júnior (2005) e Melo Júnior et al. (2007) quantified the zooplanktonic biomass transport, with emphasis being placed on transport mechanisms and migration of Decapoda, between the Santa Cruz Channel (in its north mouth, Barra de Catuama) and the adjacent shelf in the estuarine system of Itamaracá. For so, samplings were performed in august 2001 at 3 stations each 3 hours, utilizing plankton net with 300 µm of meshing size. The values of zooplankton biomass found in Barra the Catuama were considered relatively high, primarily during the spring tide and the nocturnal period; the peak of biomass transport were associated to high densities of Brachyura larvae, Copepoda Calanoida and Sergestoida. There were identified 29 taxa of planktonic Decapoda, highlighting the initial stages of *Lucifer faxoni*, *Acetes americanus*, *Pinnixa* spp., Ocypodidae Morfotipo A, *Uca* spp., *Petrolisthes armatus*, *Upogebia* spp. and Alpheidae. The authors confirmed the function of tropical estuaries as source of Decapoda larvae for coastal areas. The Decapoda larvae are exported in the Santa Cruz Channel to the adjacent coastal shelf, however the high number of larval stages in large part of identified taxa suggest that the development of these species occurs in the region near Barra de Catuama. Therefore, the authors concluded that the exportation in the Santa Cruz Channel is high, although differently from other locals, the importation is also high, possibly due to the presence of reefs and seagrasses in the shelf direction, creating a distinct productive environment.

After a series of researches, Schwamborn et al. (2008) observed that Barra de Catuama is a corridor of zooplankton biomass exchange between the Santa Cruz Channel and the adjacent coastal shelf. The majority of species and the larval stages of Decapoda showed a characteristic pattern of vertical migration, which were synchronized with the daily tidal cycles, reinforcing the estuarine retention or the estuary exportation.

A new large project was implanted from 2001, and Melo Júnior et al. (2012) published the result of the influence of the tidal cycles and photoperiod over the planktonic larvae flux of *Petrolisthes armatus* at Barra de Catuama. This study used the same sampling methodology as Melo Júnior (2005) and Melo Júnior et al. (2007). In every station, samples were collected in three or two depths, with assistance of a suction pump attached to a planktonic net with 300 µm of meshing size. During the flood tides, the larvae were more concentered in the middle and surface layers, preventing the transport to inner regions. On the other hand, during the ebb tides, the highest concentrations were found in the deep layers, preventing a higher exportation. Therefore, the authors concluded that the dynamics of larval flux of *P. armatus* related to the photoperiod was characterized for a vertical migration associated to the tidal regime, suggesting that the development of this Decapoda apparently occurs in the adjacent inner shelf of the estuarine ecosystem of the Santa Cruz Channel. Melo Júnior et al. (2016) also concluded the same, that the exportation of the larval stages of almost 27 taxa of Decapoda is to the adjacent inner shelf area, corroborating the result achieved by Schwamborn et al. (2008).

Silva-Falcão et al. (2007) performed a study about the photoperiodic and seasonal distribution of Brachyura zoeas in the Jaguaribe river estuary, an affluent of the Santa Cruz Channel, in 2001. The plankton samples were obtained bimonthly in two sampling stations utilizing a plankton net with 500 µm of mesh size. It was identified 14 taxa, where the family Ocypodidae, represented by larvae of *Ucides cordatus* and *Uca* spp., was the most abundant, followed by Xanthidae and Grapsidae. In the station near to the mouth, the taxa were well distributed, as well as it has been identified a higher number of families. The larvae of Ocypodidae, Grapside and Morphotype B indicated a dispersion movement to coastal areas, while the Pinnotheridae indicated a probable retention in the estuary waters. The high occurrence of zoeas in the first larval stage reinforces the significant role of the estuary as nursery to various species of crustaceans. In general, it was observed a higher number of groups that occurs preferentially in the ebb tide, being transported to the external areas of the estuary than those that predominated during flood tide.

Melo et al. (2008) evaluated the nictemeral variations of macrozooplankton over the tidal cycle between Barra Orange (South mouth) and the reef line of the estuarine ecosystem of the Santa Cruz Channel. The samplings were performed in March 2001 utilizing a plankton net 300 µm of mesh size. It was identified 48 taxa, being 26 in ebb tide with a dominance of holoplankton, and 40 in high tide, with dominance of Brachyura zoeas. The group of Copepoda was represented for 18 species, highlighting *Acartia lilljeborgi*, *Temora turbinata* and *Pseudodiaptomus acutus*. The authors determined a significant difference between the values of average density in the two tides, with higher density in ebb tide and higher diversity in high tide due to marine influence. The authors didn’t find significant differences between diurnal and nocturnal samples, which led them to conclude that the tide it is the main structuring factor of the mesozooplankton community in this area.

Studies about the demersal zooplankton, captured with traps in a set of tropical coastal habitats, were performed to allow comparison between communities (MELO et al. 2010). The sampling was performed during the dry and rainy periods in 2000 and 2001. Traps with 300 µm of mesh size, with and without artificial light, were placed at 6 pm and removed at 6 am of the next day, for three consecutive days. Eighty eight taxa of zooplankton were identified. Copepoda was the most abundant group, presenting the highest relative abundance in the seagrass and in the sandy substrate and being represented mainly by *Oithona oculata, Pseudodiaptomus acutus* and *Acartia lilljeborgi*. The authors have not found significant differences between communities of traps with and without light. In traps with light, Amphipoda and *O. oculata* were the taxa most representative; in traps without light, the main taxa was Foraminifera (> 40%).

In this study, Melo et al. (2010) also registered the species *Pseudodiaptomus trihamatus* to Itamaracá. This exotic species is native of the Indo-Pacific coastal waters and was accidentally introduced to the Northeastern coast of Brazil in 1977 (MEDEIROS et al. 1991).

Studies with more focus in one zooplankton species are rare to the region, and among them, it highlights the study performed by Cunha et al. (2012). These authors studied the population structure of the crustacean *Lucifer faxoni* (currently *Belzebu faxoni*), in the north mouth of the Santa Cruz Channel, based on samples collected with a plankton net with 300 µm of meshing size, in august 2001. The highest values of abundance found were of larval forms, in the station nearest to the continent, during the nocturnal period and in ebb flood tide. The authors observed a selectivity to the different stages of the life cycle of *L. faxoni* (occurrence local, period of the day and tide) as strategy of survival and better development.

Between 2003 and 2008 emerged a new project for Itamaracá entitled "Millenium Institute - Use and Appropriation of Coastal Resources - RECOS" funded by Ministry of Science and Technology (MCT), through the CNPq (Conselho Nacional de Desenvolvimento Científico), having the researches with zooplankton been inserted in the research group "Environmental Quality and Biodiversity". This project had as goal study the zooplankton, focusing the biodiversity and the species indicators of environmental quality. Within the specific objectives, the project performed qualitative and quantitative surveys of zooplankton in the estuarine system of Itamaracá, emphasizing the indicator species of environmental conditions, in order to diagnose the alteration processes of water quality; as well as to establish the zooplankton relations with the physical and chemical characteristics of the environment, and with the other components of biota.

In this new project, Santos (2008) and Santos et al. (2009) studied the zooplankton of the Botafogo and Carrapicho river estuaries through bimonthly samplings performed between August 2003 and August 2004, over two transects: one along the Botafogo river (pollution gradient) and other along the Carrapicho river (control), where were delimitated 4 sampling stations. The samplings were performed with a plankton net 300 µm of mesh size. Thirty-one taxa have been identified for the Carrapicho river estuary, with the dominance of holoplanktonic species, being the Copepoda *Acartia lilljeborgi* the dominant species, although it occurred the dominance of meroplankton, mainly Decapoda larvae, during certain periods of year. For the estuary of the Botafogo river, it has been identified 24 taxa, outranking the meroplankton, with Decapoda larvae as the most representative group. Species indicators of pollution were more restricted to the Botafogo river estuary, as larvae of the family Spionidae (Polychaeta). In relation to planktonic biomass, it was registered that the Carrapicho river estuary was more productive than the Botafogo river estuary. The diversity and evenness in the two estuaries were low, which indicated an unbalanced community of organisms in the two areas.

Continuing the studies within the Millennium project, Lucas (2006) and Lucas et al. (2008) characterized the seasonal variation of zooplankton in the estuary of the Botafogo and Siriji rivers (Santa Cruz Channel). The plankton samplings were performed in May, November and December 2004, with two nets one 68 µm and another 300 µm of mesh size, through surface and subsurface hauls. The microzooplankton presented higher values of abundance than the macrozooplankton, indicating that the community has a higher contribution of lower size individuals. For the two studied estuaries, the organisms that dominated were *Oikopleura dioica* and *Oikopleura* spp., *Acartia lilljeborgi*, *Pseudodiaptomus acutus*, *Oithona oswaldocruzi*, *Oithona* spp. and Copepoda nauplius, among the holoplanktonic, and Grapsidae/Ocypodidae/Majidae (zoea I), among the meroplanktonic. The diversity values were low (< 2 bits.ind^{-1}) as mentioned by Santos (2008) and Santos et al. (2009), and the evenness values suggested environmental perturbation over this community.

Neumann-Leitão (2010) studied the zooplankton as indicator of environmental quality in the estuary of Botafogo and Carrapicho rivers in the ecosystem of Itamaracá, from April 2003 to August 2004. The sampling was performed as in Santos (2008), being utilized, in the present study, a plankton net with 200 µm of mesh size. For the set of the two estuaries, it was identified 29 taxa common to the two estuaries. Copepoda outranked with 15 species, being the most abundant and considered indicator of the area *Acartia lilljeborgi*, *Temora turbinata* and *Parvocalanus crassirostris* (the first two are also indicators of biomass stock and of secondary production of both estuaries). Among the meroplankton, outranked the larvae of Cirripidea (*Balanus* sp.) and Brachyura zoea. *Acartia lilljeborgi* was also the key-indicator species of the Carrapicho river estuary. The higher abundance, biomass and secondary productivity were registered in the Carrapicho river estuary, reaching four times more the abundance and nearly two times more in relation to the productivity of the other estuary. It was registered a high quantity of Ctenophora, mainly in October 2003, demonstrating a probable response to the environmental imbalance. It was estimated a high secondary productivity in the least impacted environment (Carrapicho river), either comparing with the Botafogo river estuary (more impacted), as for other marine and estuarine tropical and subtropical environments, denoting that this system must exercise a key role in the ecotrophic dynamics of the Itamaracá ecosystem.

In the "Millenium Institute" project, Barreto (2009) emphasized the microzooplankton and studied its space-time variation in the Botafogo river estuary, as well as the factors that influences the structure of this community. Samplings were carried out between March 2007 and February 2008, using a plankton net with 64 µm of mesh size, in three stations. The author managed to conclude that the microzooplanktonic community presented a minor space-time variation, since its species composition was stable over the year. The holoplanktonic organisms were dominant outranking Copepoda (nauplius, copepodites, adults of *Oithona hebes*, *Acartia lilljeborgi*, *Parvocalanus crassirostris* and *Euterpina acutifrons*). In addition to these organisms, *Favella ehrenbergii*, Gastropoda (véliger) and *Oikopleura dioica* were also representative to the area.

The 2010s decade: The stagnation in the studies

In the year of 2014, Freire et al. (2014) investigated the presence of the hydromedusa *Blackfordia virginica* in the coast of Pernambuco and Sergipe states, in the Northeast of Brazil. For the estuarine system of the Santa Cruz Channel, the authors found this species in samples of the years 1996, 1998, 2000. Performing a research in the grey literature, they found references that suggest that *B. virginica* was present in the Santa Cruz Channel for at least five decades. They concluded, that *B. virginica* was well established in the region since many decades ago, and constituted an exotic component of the community.

In 2014, a new project "Studies about the dissolved inorganic carbon cycle in coastal areas of Northeast and North of Brazil and its relation with the processes of marine acidification - DICAM" was developed. The objective of this project was to perform a study about the spatial and seasonal distribution of the Dissolved Inorganic Carbon (DIC) in two coastal areas with different levels of anthropic occupation, one in the Northeast of Brazil, in the estuarine system of the Santa Cruz Channel and another in North of Brazil (Bragança - PA), being used the Rocas Atoll and the Fernando de Noronha Archipelago as controls. However, few samplings were performed in relation to the zooplankton in the area, opening a gap in the monitoring of this group over the years.

At the end of the 2010 decade no large project was implanted, and it can be inferred that this decade was characterized by a clear decrease in the amount of studies related to zooplankton for the estuarine system of the Santa Cruz Channel. Few initiatives have been taking and no project was established with the objective of monitoring the zooplankton in this ecosystem.

CONLUSIONS

In the 1970 and 1980 decades, the most part of the projects consisted of the zooplankton as a whole, describing its composition, distribution, abundance, diversity, being the group of Copepoda the dominant with higher frequency of occurrence and abundance. It was highlighted the large amount of studies related to the zooplanktonic organisms of natural ponds, mainly the Rotifera.

The 1990 decade was marked by a great amount of projects, with more elaborated studies, resulting in the most studied estuarine areas of Brazil. This decade published studies about fish larvae and protozooplankton, and showed an increase in the number of studies about Decapoda larvae. The transition between the 1990 and 2000 was marked by the publication of the first book about the estuarine system of the Santa Cruz Channel, with one chapter dedicated only to the zooplankton.

In the years 2000, it could be observed an intensification in the studies about the flux and transport of the zooplanktonic organisms in the estuarine system of the Santa Cruz Channel, through a large project. There was, still, another project that aimed to study the zooplankton as environmental indicator and also contributed to a better understanding of the area. However, despite of all the progress and the large number of studies in the previous decades, the 2010 decade was marked by the absence of studies and projects. This resulted in one large gap in the knowledge and the monitoring of the area, making it impossible to know the real conditions of this ecosystem and what is expected for a nearby future.

The most studied groups were the Copepoda and the Decapoda. Among the Copepoda, outranked *Acartia lilljeborgi* (dominant during the 35 years surveyed), *Oithona* spp., *Euterpina acutifrons*, *Parvocalanus crassirostris* and *Temora turbinata*. It was found the presence of exotic species (*Temora turbinata* e *Pseudodiaptomus trihamatus*). Among the Decapoda, it was important Brachyura larvae and the studies about its dispersion. It was registered the occurrence of an exotic hydromedusa (*Blackfordia virginica*) in the studied area.

A clear discontinuity was observed in studies in the estuarine system of the Santa Cruz Channel. This discontinuity makes the future an interrogation point. We reinforce the importance of a continuos monitoring, with new projects of long-term duration.

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3.2 COPEPOD COMMUNITY RESPONSES TO TEMPERATURE, MAINLY *ACARTIA (ODONTOCARTIA) LILLJEBORGI* GIESBRECHTI, 1889, IN A TROPICAL ESTUARINE SYSTEM

INTRODUCTION

The tropical zooplankton communities are predisposed to be more sensitive to climatic changes, including the effects of the temperature, due to their low environmental variability from their natural environments (SUNDAY et al., 2011). The small copepods (e.g. *Acartia* and *Oithona*) are the main portion of zooplankton in estuarine areas, and undoubtedly the most abundant metazoans on Earth. Moreover, because of its great abundance, usually comprising between 50 and 80% of the community by number (WICKSTEAD, 1976), and its quick response to environmental changes, they are considered good environmental indicators (KJØRBOE, 2011).

The body size variations in Copepoda have been widely studied because they affect the main organism's vital rates, such as feeding, growth, metabolism and reproduction (GLAZIER, 2005; ARENDT, 2011; KIØRBOE, 2011; HIRST et al., 2014; KIØRBOE; HIRST, 2014). Then, understanding what promotes these variations in body size is of great importance. The body size of Copepoda is influenced by environmental characteristics, such as changes in temperature and food availability (ASHJIAN; WISHNER, 1993; HORNE et al., 2016).

Along the Brazilian coast six species of *Acartia* genus can be found (*A. danae*, *A. giesbrechti*, *A. lilljeborgi*, *A. longiremis*, *A. neligens* and *A. tonsa*) (BJÖRNBERG, 1981). Among these species, *Acartia (Odontocartia) lilljeborgi* is widely distributed in tropical and subtropical areas, being the predominant species in several Brazilian estuarine areas (MATSUMURA-TUNDISI, 1972; PARANAGUÁ; NASCIMENTO-VIEIRA, 1984; GAETA et al., 1990; DIAS, 1999; WANDENESS et al., 1997; ARA, 1998). Particularly, in the tropical area in question here, the Santa Cruz Channel, *A. lilljeborgi* is considered a key species, dominating the area (PARANAGUÁ et al., 1979; NASCIMENTO, 1981). In addition, after the study that was driven by Björnberg (1962), this species started to be considered an indicator of estuarine influence in coastal waters.

Several biological and ecological aspects from *A. lilljeborgi* have been studied, like growth and development (BJÖRNBERG, 1972; GÓMEZ-GUTIÉRREZ et al., 1999), seasonal variation abundance (MATSUMURA-TUNDISI, 1972; LOPES, 1994), tolerance to salinity, temperature and/or salinity range to the occurrence (BJÖRNBERG, 1972; NASCIMENTO, 1981; LIRA et al., 1996), egg production rate (HOPCROFT; ROFF, 1998; GÓMEZ-GUTIÉRREZ et al., 1999) and population production rate (ARA, 2001). However, studies about the relation between body size and temperature variations have not been realized yet.

The response of copepods to the increase of water temperature can be observed at the individual or population level (DAUFRESNE et al., 2009). The *Oithona* genus has been considered the most abundant and omnipresent marine copepod in the oceans around the world (GALLIENE; ROBINS, 2001). Besides *Acartia*, this genus is also very abundant and present in zooplankton samples in the Santa Cruz Channel (PARANAGUÁ; NASCIMENTO, 1984; NEUMANN-LEITÃO, 1995; NEUMANN-LEITÃO et al., 2001).

The changes in the body size of *A. lilljeborgi* can show the population response to the temperature change, as long as the changes in the relative abundances of *Oithona* genus and *A. lilljeborgi* in relation to the copepods of the area can show the community response. Thus, the main hypothesis raised in this paper is that the temperature has an effect on the body size of *Acartia lilljeborgi* as also on the copepod community structure, through a change in the relative abundances of *Oithona* genus and *A. lilljeborgi* in the community.

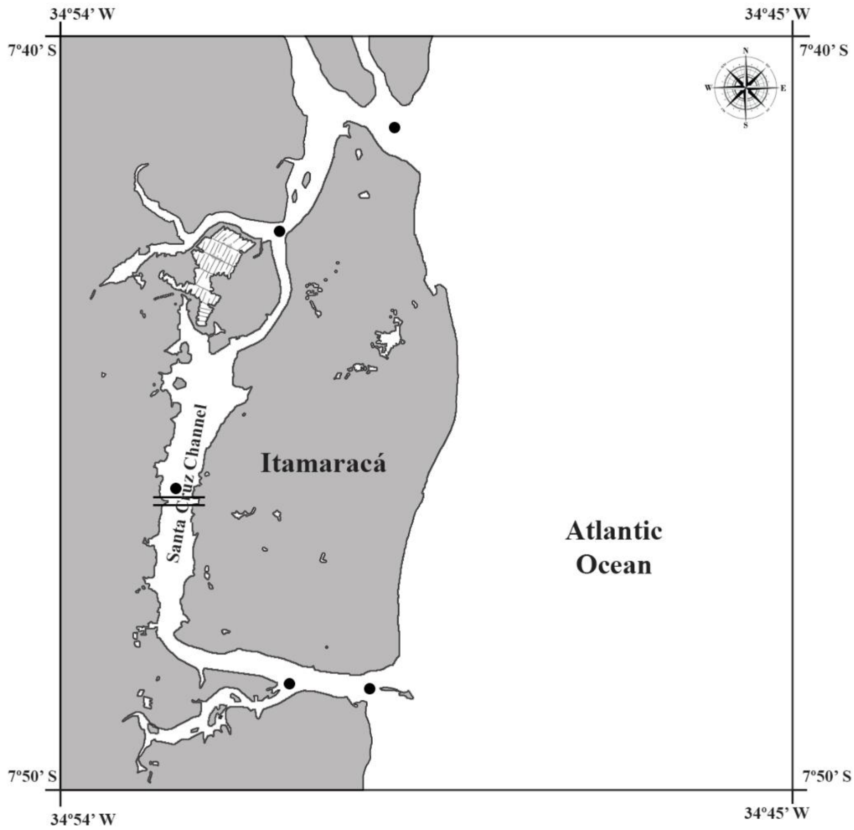
MATERIAL AND METHODS

Material survey and choice of analyzed samples

Firstly it was carried out a survey on zooplankton samples from Santa Cruz Channel estuarine system, stored in the Museum of Oceanography of UFPE (MOUFPE), from collections made from the 1970s onwards. After that, the samples obtained with a plankton net 64 µm mesh size, and in a better stage of conservation were selected to be analyzed. It was chosen samples from the years 1975 (October and November), 1995 (March), 1996 (December) and 2007 (March, November, and December). Three samples were analyzed from each selected year, always from the dry season to exclude the seasonality. *A. lilljeborgi* and *Oithona* genus were identified and numbered, while measurements were made to *A. lilljeborgi*.

New samples with the same net size were collected in 2016 (January) in the Santa Cruz Channel. We used the same methodology as the old samples, through sub-superficial 3 minutes hauls, and fixation with formalin buffered solution (4%). All these samples (olds and news) were from different points of Santa Cruz Channel. It is important to highlight that, according to Paranaguá et al. (2000), besides the great extension of Santa Cruz Channel estuarine system, the organism’s composition is similar in all the area, with a trend of higher diversity from the continent to the mouths of the Channel, where the salinity variations are less intense. The locations of these samples are shown in Figure 1.

Figure 1 - Santa Cruz Channel estuarine system, Pernambuco, Brazil. The black dots represent the sampling stations.



Fonte: A autora.

Laboratory analysis

In the laboratory, the samples were diluted to values between 25 and 2200 mL, being one aliquot of 1 mL analyzed for all the samples under a compound microscope using a Sedgwick-Rafter chamber. The total number of Copepod, juveniles and adults from *Oithona* genus and *A. lilljeborgi* were counted in each aliquot. After that, each sample was concentrated to facilitate the catch of *A. lilljeborgi* individuals to measurement. The body size from 20 adult females of *A. lilljeborgi* was measured from each sample. When the abundance of the given species was very low, it was taken a maximum of 15 aliquots from the sample, where all the females from the species were measured.

Põllupüü (2007) studied the effects of preservation with formalin on body size of copepod *Acartia bifilosa* and did not found any significant differences on this parameter between live and preserved organisms. Thus, this study is going to considerate that are no differences on *Acartia lilljeborgi* body size, enabling the comparison from 1975 measurement values with recent ones.

Temperature data

The temperature data used in this study are originated from Ezkinazi-Leça et al. (1984), Porto-Neto et al., (1999), Schwamborn et al., (2001), Nascimento Filho (2014). In addition, temperature data from in situ sampling in January 2016 were also utilized here (Table 1). All the temperature values taken were from the same months of the samples analyzed.

Data analysis and statistics

The relative abundances of *Oithona* genus and *A. lilljeborgi* in relation to the total of copepod was calculated using a simple division between the total number of *Oithona*/*A. lilljeborgi* individuals by the total number of copepod (P% = NOithona or Acartia/NCopepoda x 100).

To the statistical tests, the data had the normality tested using the Shapiro-Wilk test. Parametric data were compared using an analysis of variance (ANOVA, one-way); as long as for non-parametric data the ANOVA Kruskal-Wallis was used. To verify the existence of a relation between the temperature and body size, abundance and secondary production, simple regressions and Pearson's correlation test were used. All the analysis were performed using the program SigmaPlot 12 and values of $p < 0.05$ were considered significant.

RESULTS

Temperature data

The temperature increased significantly from 1975 to 2016 (K-W, $p = 0.013$), with a minimum value of 29.16ºC (± 0.46ºC) in 1975 and a maximum of 30ºC in 1995, 1996 and 2016, with a significant difference of 0.84ºC (t-test, $p = 0.035$) (Table 2).

Table 1 - List of the studies utilized to obtain the values of temperature, with the year of publication, the title of the study, the method utilized to obtain the temperature, referred period and author.

Publication	Title	Method	Period
Eskinazi-Leça et al., 1984	Estudo ecológico da região de Itamaracá, PE-BR. XXIV. "Standing Stock" do fitoplâncton do estuário do rio Botafogo, durante janeiro a dezembro/75	Inversion thermometer attached to a Nansen bottle	Jan to Dec/1975
Porto-Neto et al., 1999	Variação sazonal e nictemeral do zooplâncton no Canal de Santa Cruz, Itamaracá, PE, Brasil	Digital thermometer	Jul and Dec/1996
Schwaborn et al., 2001	Distribution and dispersal of Decapod Crustacean Larvae and Other Zooplankton in the Itamaracá Estuarine System, Brazil	Conductivity probe	Feb and Mar/1995; Mar, Apr, and May/1996
Nascimento Filho, 2014	Uso de índices ambientais como ferramentas de avaliação do estado trófico (qualitativo e quantitativo) de estuários no estado de Pernambuco	Regular thermometer and CTD	Mar/2007 to Mar/2008
2016	*In situ* sampling	Regular thermometer	Jan/2016

Fonte: A autora.

Table 2 - Temperature values from Santa Cruz Channel in 1975, 1995, 1996, 2007 and 2016. Mean = average from the studies months; SD = standard deviation; Min = minimum value; Max = maximum value.

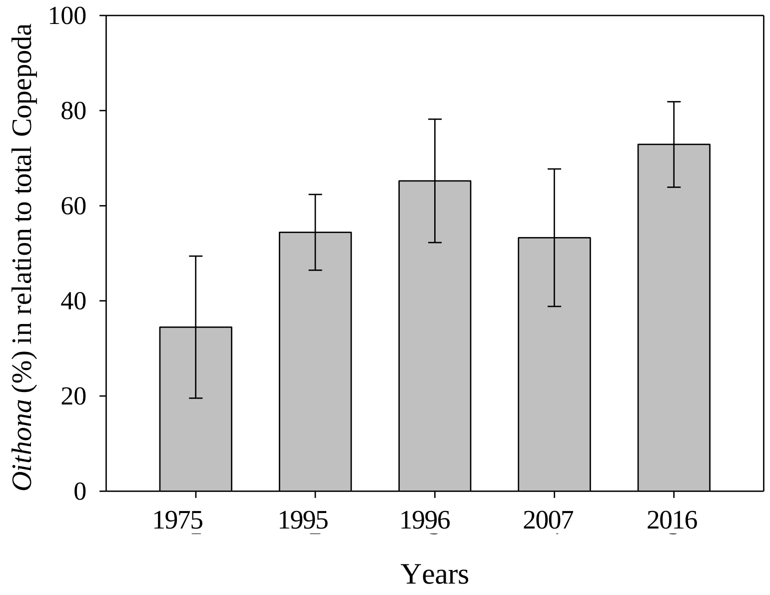
	Temperature (ºC)			
	Mean	SD	Min	Max
1975	29.16	0.46	28.63	29.43
1995	30	-	30	30
1996	30	-	30	30
2007	29.78	0.27	29.47	29.93
2016	30	-	30	30

Fonte: A autora.

Relative abundance of Oithona in relation to total Copepoda

In relation to the mean values from relative abundance of *Oithona* genus in relation to total Copepoda, it was observed a minimum value of 34.48% (± 14.94%) in 1975 and a maximum of 72.88% (± 9.00%) in 2016, with a significant difference of 38.4% between those years (t-test, p = 0.019). The mean values increased with the time (Figure 2), presenting significant differences between the years (ANOVA, p = 0.032).

Figure 2. Mean relative abundance of *Oithona* genus in relation to total Copepoda on the studied years (1975, 1995, 1996, 2007 and 2016).

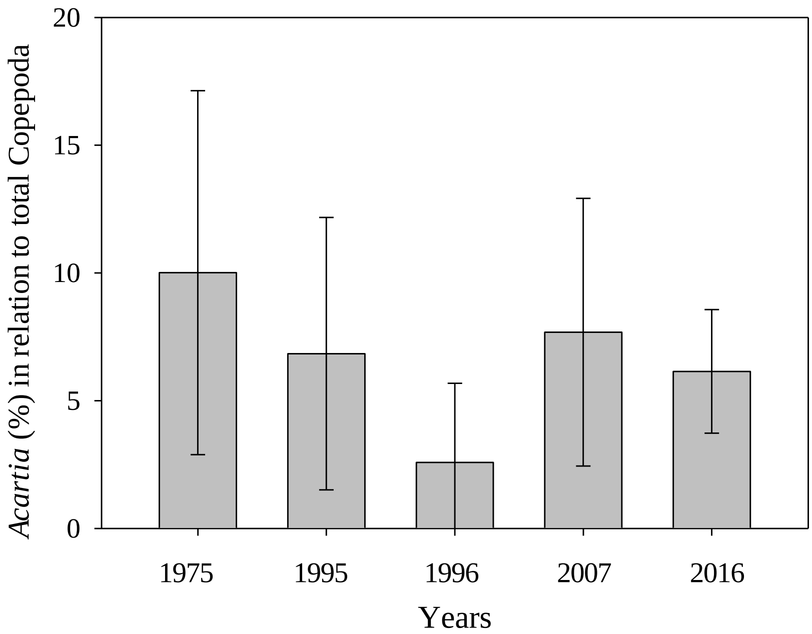


Fonte: A autora.

Relative abundance of Acartia lilljeborgi in relation to total Copepoda

In relation to relative abundance of *A. lilljeborgi* in relation to total Copepoda, it was 'not observed a clear pattern, without significant differences (ANOVA, p = 0.501), with the mean values decreasing from 1975 to 1996, followed by an increase in 2007 and a slightly decrease in 2016 (Figure 3). It was observed a minimum value of 2.58% (± 3.10%) in 1996 and a maximum of 10.01% (± 7.13%) in 1975, without significant difference between those years (T-test, p = 0.173).

Figure 3 - Mean relative abundance of *Acartia lilljeborgi* in relation to total Copepoda on the studied years (1975, 1995, 1996, 2007 and 2016).

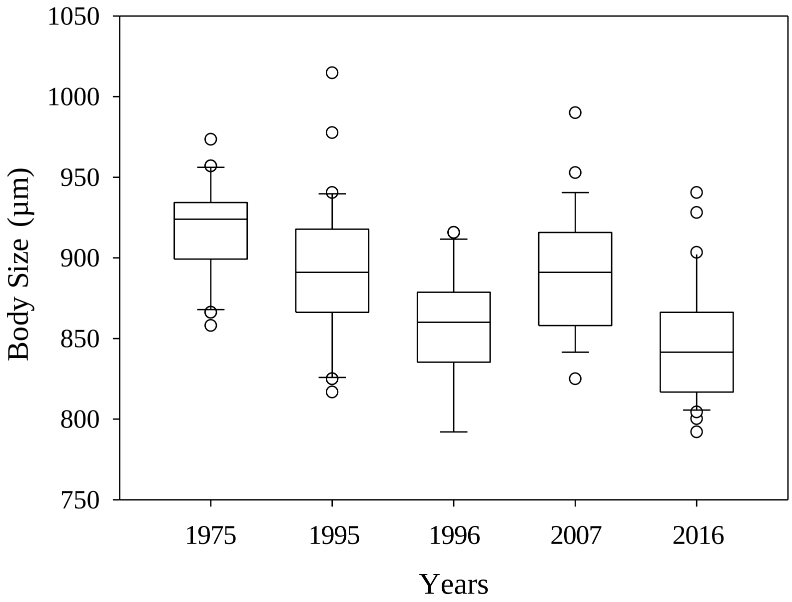


Fonte: A autora.

Acartia lilljeborgi body size

The *A. lilljeborgi* mean body size values decreased from 918.23 µm (± 49.51 µm) in 1975 to 844.29 µm (± 50.13 µm) in 2016, with a significant difference (t-test, p = 0.007) of 73.94 µm between these years (Figure 4). It is possible to observe a decrease in mean body size of *A. lilljeborgi* with the years that was confirmed statistically (ANOVA, p = 0.01).

Figure 4 - Mean body size (µm) of *A. lilljeborgi* in the years 1975, 1995, 1996, 2007, 2016. The middle line inside each box is the median, the solid lines above and below on the box represent first and third quartiles, respectively; the vertical lines represent the standard deviation; and the open dots represent the outliers.



Fonte: A autora.

Regressions and Pearson's correlation

Body size and relative abundances of *Oithona* genus and *A. lilljeborgi* were compared to the temperature data to search for possible correlations (Table 3). In relation to body size, it was found a significant and negative correlation with the temperature (p = 0.032; r = -0.553). For the relative abundances, the *Oithona* genus presented a significant and positive correlation with the temperature (p = 0.002; r = 0.730); as long as *A. lilljeborgi* showed no significant difference nor correlation with the temperature. In addition, body size and relative abundances of *Oithona* genus and *A. lilljeborgi* were compared between each other, being the *Oithona* genus significant and negatively correlated (p = 0.017; r = -0.606) and *A. lilljeborgi* showing a positively but not significant correlation (p = 0.051; r = 0.512).

Table 3 - Regression equations for body size vs. temperature, relative abundance of *Oithona* genus vs. temperature, relative abundance of *Acartia lilljeborgi* vs. temperature, body size vs. relative abundance of *Oithona* genus, and body size vs. relative abundance of *Acartia lilljeborgi*. BS = body size; T = temperature; %O = relative abundance of *Oithona* genus in relation to total Copepoda; %A = relative abundance of *Acartia lilljeborgi* in relation to total Copepoda.

Regression Equation	r^2	p value	Pearson's coefficient
BS = 2346.537 - (49.298 x T)	0.306	0.032	-0.553
%O = -9.155 + (0.326 x T)	0.532	0.002	0.730
%A = 0.360 – (0.00985 x T)	0.006	0.779	-0.079
BS = 946.331 – (120.855 x %O)	0.368	0.017	-0.606
BS = 853.637 + (366.929 x %A)	0.263	0.051	0.512

Fonte: A autora.

DISCUSSION

In this study, it was observed an increase in the relative abundance of *Oithona* genus, an absence of a clear pattern of the relative abundance of *Acartia lilljeborgi* in relation to total Copepoda, a decrease in the body size of *A. lilljeborgi*. It was also observed that the relative abundance of *Oithona* genus and body size of *A. lilljeborgi* are negatively correlated between each other. In addition, these two parameters showed a significant correlation with the temperature, that it was not observed to relative abundance of *A. lilljeborgi*, that is possibly one of the main drivers of the changes in the community. Thus, the main hypothesis raised here was accepted: the temperature has an effect on the body size of *Acartia lilljeborgi* as also on the Copepod community structure.

The recent success of Oithonidae family particularly in coastal waters appears to be a global phenomenon (CHEW; CHONG, 2016). The significant increasing in *Oithona* genus percentage is changing the Copepod composition in the Santa Cruz Channel estuarine area and is an expected prediction, since several authors have been related that mainly warmer waters cause the enhancing of proportion of small-sized species (DAUFRESNE et al., 2009; DAM, 2013; RICE et al., 2014). Daufresne et al. (2009) found that the increasing temperature acts on communities, populations, and individuals through changes in species composition, such as found in this study, growth, and reproduction.

Several authors reported a change in community structure, where communities dominated by *Acartia* became dominated by *Oithona* (e.g. ITOH; NISHIDA, 2015; RICE et al., 2015; UYE, 1994; WINDER; JASSBY, 2011). However, all of these studies were performed on cold regions (Tokyo Bay, Osaka Bay, Long Island Sound and San Francisco Estuary). Chew and Chong (2016) were the first to observe this pattern in a tropical environment (Klang Strait, Malaysia), comparing two time periods (1985-1986 and 2014-2015). These authors investigated the effects of sea warming and other anthropogenic disturbances on Copepod community and observed that *Oithona* genus and other opportunistic species were adaptable or unaffected by these changes, increasing significantly its abundance. In addition, they also observed a low relative abundance of *Acartia* individuals (*A. spinicauda* and *A. erythraea*), between 1 and 8%, as found in the present study, but this abundance was declining with the time, what was not found here.

Rice et al. (2015), studying the impacts of climate change on estuarine zooplankton from Long Island Sound (USA), also observed an increase in the annual percentage of *Oithona* genus of 11.3% between 1952 and 2010-2011. The same pattern was found in this study, though the increase in the present study was even greater (38.4%). The authors, as others (UYE, 1994; ZAMORA-TEROL et al., 2014) suggested that this increase might reflect the ability of the *Oithona* genus to graze on and its preference for flagellates and smaller preys that flourish on warmer conditions.

Not only because the dietary preference, the *Oithona* genus higher abundance around the world can be explained also by other physiological and behavioral responses that make them more competitive than other copepods, here the larger-bodied *A. lilljeborgi*. In this study was observed a positive and significant correlation between the temperature and the relative abundance of *Oithona* genus. These organisms developed low metabolic and high reproduction rates with an increase in temperature (CASTELLANI et al., 2005; WARD; HIRST, 2007; ALMEDA et al., 2010); its high abundance indicates that these higher reproductive rates exceed the loss rates, as observed by Chew and Chong (2016) for *Oithona simplex* and *O. attenuata*.

The body size is an essential biological characteristic that is as important as other several ecological properties (e.g., fecundity, population, growth rate, competitive interactions) (MILLIEN et al., 2006; ARENDT, 2007). Among the environmental factors that can influence the body size of Copepoda, the temperature has been recognized as one of the most important by several authors (e.g. MCLAREN et al., 1989; RICCARDI; MARIOTTO, 2000; RICE et al., 2015).

It was found here a decrease in the body size of *A. lilljeborgi*, a dominant Copepod in the Santa Cruz Channel estuarine system over the past 40 years. According to Daufresne et al.

(2009), “the reduced body size is a third universal ecological response to global warming among ectotherms in aquatic systems besides the shift of species range toward higher altitudes and latitudes and the seasonal shifts in life-cycle events”. The temperature-size rule says that an increase in temperature decreases the individual body size of ectotherms, via decreasing development time and final size of adults (ATKINSON, 1994; FORSTER et al., 2012).

In a general way, Daufresne et al., (2009) found a negative effect of increases in seawater temperature on the body size of aquatic ectotherms from individual to community structure level. Specifically, such as found here, Rice et al. (2015) observed a decreasing in body size of *Acartia tonsa* and *Acartia hudsonica* by comparing results from 1952-1953 with others from 2010-2011, which corroborates our results. These authors related this decreasing to the increase in surface seawater temperature, suggesting that long-term increased temperature conditions can lead to consistently smaller copepods due to physiological changes led by temperature-size rule. The results found here also corroborates the conclusion of Chew and Chong (2016) that said that the larger-bodied copepods are clearly suffering more with the anthropogenic impacts than the small ones.

The negative correlation between the body size of *A. lilljeborgi* and relative abundance of *Oithona* genus and the absence of significance between the body size and relative abundance of *A. lilljeborgi*, strongly indicates that the trophic web in the Santa Cruz Channel estuarine system is changing towards a community dominated by one of the smallest genera of Copepoda. The overfishing, that is a known impact factor in this area (BARROS et al., 2000), allied to the increase in the Ctenophora *Mnimeopsis leidyi* (Neumann-Leitão, personal communication) that feeds upon large zooplankton, are contributing to increasing the number of smaller-sized copepods.

Moreover, an increase in the proportion of one of the smallest Copepoda genus and a decrease in the body size of one of the most dominant Copepoda genus matches with the predictions made by Daufresne et al. (2009). These authors discussed the impact of climate change on aquatic ecosystems, mainly on ectotherm organisms, concluding that the long-term increasing on temperature would cause a universal decrease in the size of those organisms. These authors pointed out that at the population level, the juveniles would mature more rapidly and begin the reproduction at smaller sizes leading to a decrease in individual mean size; and at the community level, it would occur a change in proportion as much as endemic, smaller copepods would become more relatively abundant.

Despite all shown here, we do not believe that the temperature is one of the main but is not the only factor affecting the body size of *A. lilljeborgi* and the relative abundance of *Oithona* genus, as is possible to visualize on the regression values. Several other authors also raised this question, pointing out that other anthropogenic factors, mainly the eutrophication, acts as a determining factor in Copepoda community structure (e.g. PARK; MARSHALL, 2000; CHEW et al., 2015; CHEW; CHONG, 2016). Here, we suggest a continuation of this study, with more months/years being analyzed, to search for more interactions, as well as experimental work to support field results.

3.3 EFFECTS OF ENVIRONMENTAL PARAMETERS ON BODY SIZE, PRODUCTION, AND ABUNDANCE OF *OITHONA HEBES* GIESBRECHTI, 1891 IN A TROPICAL ESTUARY

INTRODUCTION

Copepods are important metazoan secondary producers in the estuarine realm. They are known for their ecological importance as the main food item for many invertebrates, fish larvae, and juveniles, consequently playing an important role in controlling mollusks, crustaceans and fish recruitment, among others (MCLUSKY; ELLIOT, 2004). They are important links in the flow of organic carbon between primary producers and large-sized consumers (HOPCROFT; ROFF, 1996; SAIZ et al., 1997; CALLIARI et al., 2009), and respond quickly to environmental changes, representing good environmental indicators (KJØRBOE, 2011). In the mesozooplankton fraction, copepods are mainly represented by small adults (FRONEMAN; MCQUAID, 1997; PALOMARES-GARCÍA et al., 2006; CALBET, 2008).

According to Turner (2004), small planktonic marine Copepods, including the *Oithona* genus, are undoubtedly the most abundant metazoans on Earth and particularly important due to their feeding on autotrophic and heterotrophic protists. Especially in case of small-sized copepods, there are evidences that they dominate in terms of abundance and sometimes in terms of biomass and grazing pressure on the phytoplankton (DAM et al., 1993; ROMAN et al., 1993; FRANZ; GONZALEZ, 1997). In addition, the nauplii and copepodite and adult stages of smaller copepods are important food resources for critical larval stages of many commercial fish (CONWAY et al., 1991, 1996, 1998). In tropical estuaries, they have been considered very numerous and frequent (LANSAC TÔHA; LIMA, 1993; FRONEMAN; MCQUAID, 1997; HOPCROFT et al., 1998; NEUMANN-LEITÃO et al., 2001; MCKINNON et al., 2008).

Among these small-sized copepods, the marine *Oithona* genus has been considered the most abundant and ubiquitous copepods in the world's oceans (Gallienne & Robins, 2001). The species *Oithona hebes* has been cited as very abundant in tropical coastal-marine systems in Brazil (e.g.: PARANAGUÁ; NASCIMENTO, 1984; NEUMANN-LEITÃO, 1995; PORTO NETO et al., 1999; NEUMANN-LEITÃO et al., 2001; DIAS et al., 2009). Besides, they adapt well to laboratory rearing (euryplastic pelagic), with a short life cycle, showing good survival, the quantity of egg-bearing females and nauplii production (TORRES-SORANDO et al., 2003).

Oithona hebes was the most abundant species in the Plankton Collection samples (64 µm mesh size net) from the Museum of Oceanography of the Federal University of Pernambuco (Brazil), collected monthly in 1975 and in 2007-2008 in the same stations in the Botafogo river estuarine area. These samples were re-analyzed in order to access patterns changes in body size, abundance and production under different impacts between three decades, associating to environmental conditions, considering also climate changes effects.

MATERIAL AND METHODS

Study area

The Botafogo river is located in the North of Pernambuco state, with an extension of nearly 50 km and 248 km^2 of watershed, located mostly in rural areas. In the estuarine region, this river is drained off in the Santa Cruz Channel (Itamaracá Island, Pernambuco, Brazil) where attains an extension of around 1 km (Figure 1) (CPRH, 2006). Its margins are occupied by native rainforest and mangrove, but along its course also exists urban occupation, industrial activities, agriculture and aquaculture activities. Because of it, the Botafogo river receives industrial and domestic wastes, presenting high pollution (MELO, 2007). This situation has worsened because shrimp farms have been releasing effluents into the estuary without treatment (CPRH, 2006).

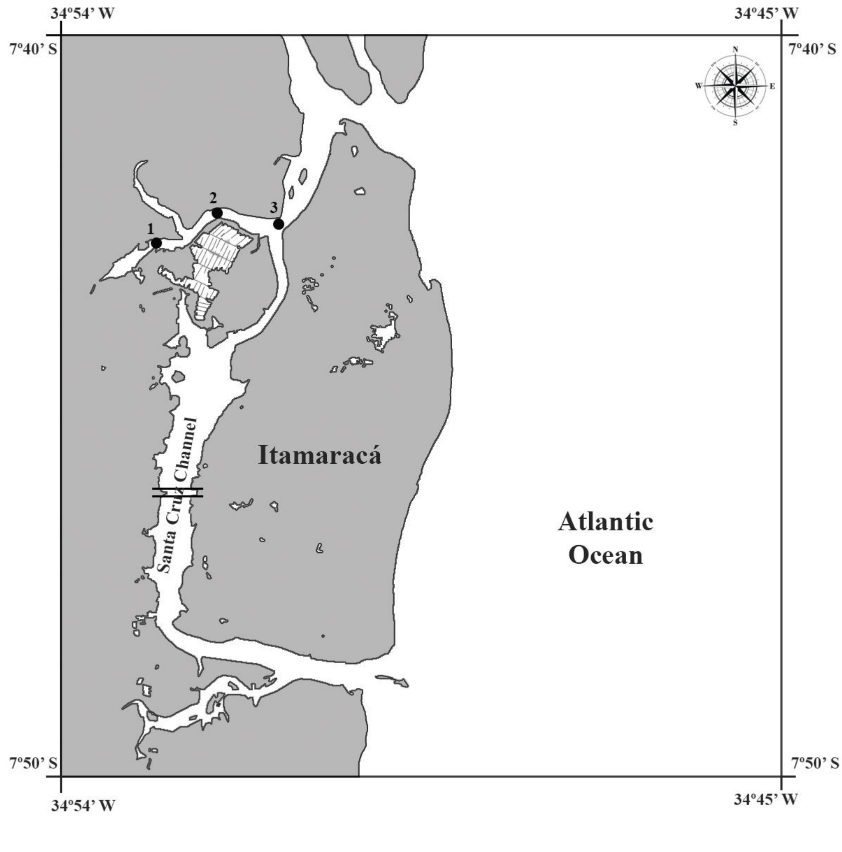
According to CPRH (2001) and Moura and Candeias (2011), from 1996 to 2011 occurred a mangrove deforestation in the area, mainly to make room for the installation of a shrimp farm. The increased activity of shrimp farming in this period, motivated by economic benefit, reached around 331%, and two large shrimp farming projects are active in the Botafogo River estuary: The Neptune Mariculture and Atapuz Aquaculture.

The climate is warm-humid, pseudo-tropical, with an annual average temperature of 24ºC and rainfall of 1500-2000 mm yr^{-1}, concentrated from March to August. The humidity is higher than 80% and predominant winds are from the southeast. According to Silva (2017) both in 1975 and 2007-2008 the clime was between La Niña and El Niño events.

Sampling

Plankton collections were carried out from January to December of 1975 and from March 2007 to February 2008, during high tide, in three stations along the Botafogo River estuary (Station 01: 7º43'S and 34º52'W; Station 02: 7º43'S and 34º53'W; Station 03: 7º43'S and 34º54'W) (Figure 1). Samples were collected through 3 minutes' on sub-superficial hauls with a plankton net 64 µm mesh size. Samples were fixed with 4% formaldehyde, neutralized with sodium tetra-borate (NEWELL; NEWELL, 1963). Hydrological data were obtained concurrently at sub-surface: the temperature (ºC) was obtained with a digital thermometer, 0.5 accuracy; the transparency (m) with a Secchi disc; salinity through Mohr-Knudsen method (STRICKLAND; PARSONS, 1965). The pH was obtained with a Beckman Zeromatic II phmeter; dissolved oxygen ($mL.L^{-1}$) through Winkler method (STRICKLAND; PARSONS, 1972) and UNESCO (1973); and, at last, chlorophyll-a ($mg.m^{-3}$) through a Micronal B280 Spectrophotometer (PARSONS; STRICKLAND, 1963).

Figure 1 - Study area and sampling stations at Botafogo estuary, Itamaracá, PE-Brazil, from January to December/1975 and from March/2007 to February/2008.



Fonte: A autora.

Laboratory procedures

In the laboratory, three 1 mL aliquot from each sample was analyzed under a compound microscope using a Sedgwick-Rafter chamber and all *Oithona hebes* counted. The prosome of 30 first adult individuals of *Oithona hebes* was measured from each sample to calculate the dry weight (DW) (µm) using the linear equation DW = 3.405 x 10^{-10} $PL^{3.463}$, where PL is the prosome length (ARA, 2001). Then, the DW was converted to carbon (C) considering that C = 0.40 x DW (POSTEL et al., 2000). Biomass values (B, mg C m^{-3}) were calculated from B = DW x D x 10^{-3}, considering DW in carbon (C), and the D = abundance (ind m^{-3}).

The *Oithona hebes* production (mg C m^{-3} day^{-1}) was calculated by the product between the instantaneous growth rate and biomass. To estimate the instantaneous growth rate (g) it was used the Hirst and Bunker (2003) model. In this model water temperature (T), dry weight in carbon (C) and chlorophyll-a (Chl) are considered. Adults and juveniles were considered together, as the equations: *H-B*: Log10 g = 0.0186 [T] – 0.288 [log10PS] + 0.417 [log10Chl] – 1.209.

Statistical analysis

In relation to the statistical tests, the data had the normality tested using the Shapiro-Wilk test: when they were parametric, the data was compared with the t-test or analysis of variance (ANOVA, one-way); when non-parametric the alternatives used were Mann-Whitney test or Kruskal-Wallis ANOVA. Simple regressions and Pearson’s Correlation Test were performed to look for relations between body size, production, and abundance and the environmental parameters. As no significant differences ($p > 0.05$) was found between stations 1, 2 and 3 we used the mean per month for all factors. All these analysis were performed using SigmaPlot 12 software and values of $p < 0.05$ were considered significant.

RESULTS

Environmental data

All the environmental parameters increased from 1975 to 2007-2008, except the water transparency (Figure 2). The increase in temperature values was 0.35 ºC, on salinity values was 0.82, on dissolved oxygen was 0.64 mL L^{-1} and on pH was 0.39. The chlorophyll-a almost doubled it mean values, with an increase of 5.46 mg m^{-3} (Table 1).

Water temperature (T-test, p = 0.522), salinity (T-test, p = 0.605) and transparency (T-test, p = 0.166) presented no significant differences between the years studied. Although, the dissolved oxygen (T-test, p = 0.045), pH (M-W, p = 0.004) and chlorophyll-a (M-W, p = 0.003) presented significant differences between 1975 and 2007-2008.

Table 1 - Environmental parameters from Botafogo River estuary in 1975 and 2007-2008. Mean = average of all months for each year; SD = standard deviation; Min = minimum value; Max = Maximum value.

Environmental Parameters	**1975**				**2007-2008**			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Water temperature (ºC)	28.59	1.44	25.3	30.80	28.94	1.25	26.10	32.00
Salinity	21.31	6.28	5.68	32.3	22.13	5.43	12.03	30.50
Dissolved oxygen ($ml.L^{-1}$)	3.34	0.94	1.63	4.73	3.98	0.89	2.60	6.03
Transparence (m)	1.41	0.63	0.30	3.10	1.14	0.50	0.20	2.10
pH	7.67	0.18	7.15	7.95	8.06	0.32	7.17	8.65
Chlorophyll-a ($mg.m^{-3}$)	6.28	4.18	2.10	20.60	11.74	5.53	3.20	28.30

Fonte: A autora.

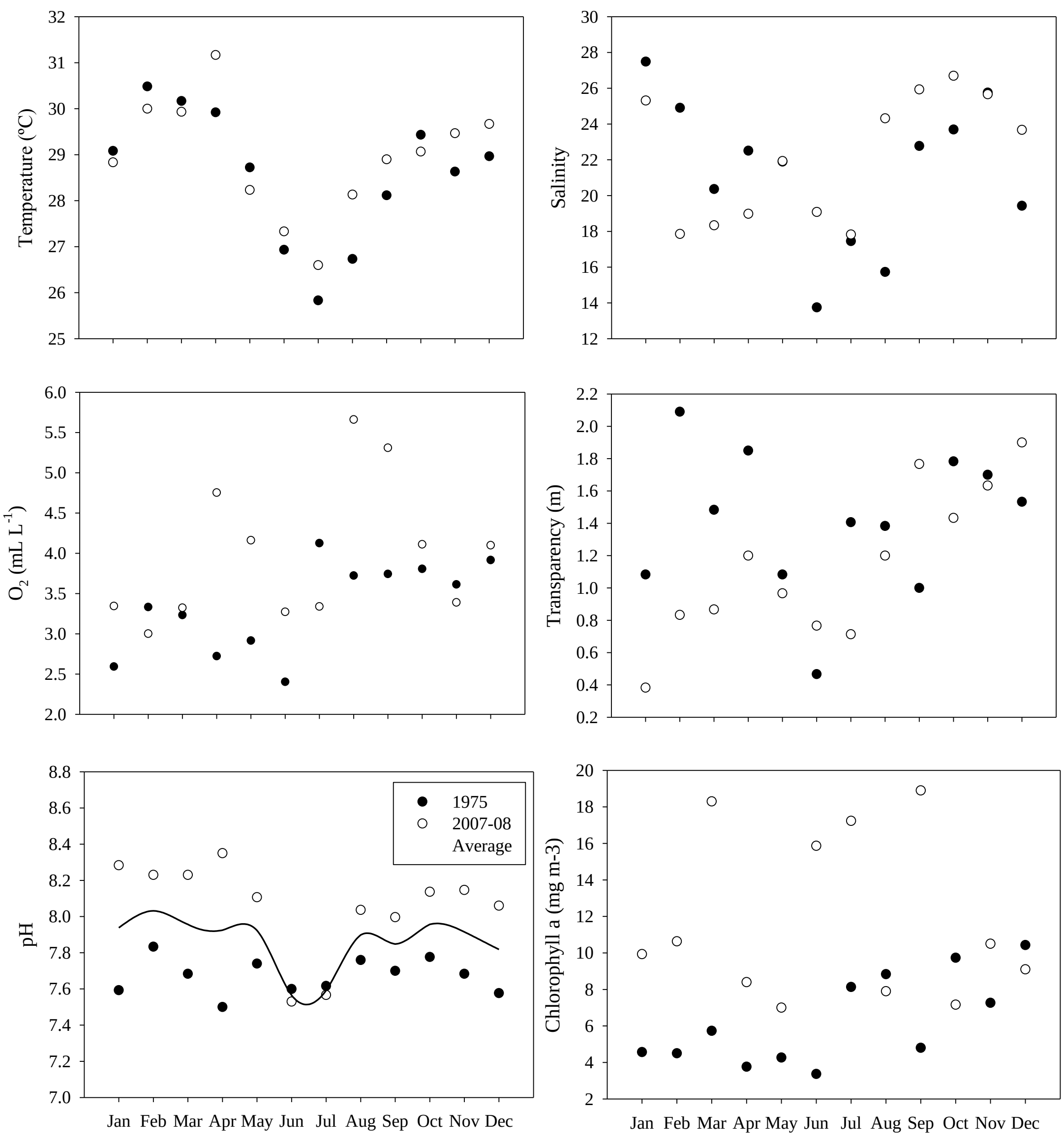
Oithona hebes data

Oithona hebes abundance in 1975 varied from 3.29 to 168.41 ind m^{-3} with an average value of 41.88 ± 38.68 ind m^{-3} (Figure 3). In 2007-2008, the abundance varied from 1.62 to 1327.21 ind m^{-3} with a mean value of 176.90 ± 267.66 ind m^{-3} (Figure 3). The abundance was higher in 2007-2008 in relation to 1975, with statistical analysis showing significant differences between the years (M-W, $p = 0.009$).

The body size of *O. hebes* in 1975 varied from 510 to 570 µm with a mean value of 541.71 ± 16.18 µm (Figure 3). In 2007-2008, the size varied from 460 to 520 µm with a mean value of 490.29 ± 14.85 µm (Figure 3). Body size presented the higher values in 1975, also with a significant difference (M-W, $p < 0.001$).

Biomass values varied from varied from 0.001 to 0.071 mg C m^{-3} in 1975 with a mean value of 0.017 ± 0.015 mg C m^{-3} (Figure 3). In 2007-2008, the values varied from 0.0004 to 0.430 mg C m^{-3} with a mean value of 0.053 ± 0.086 mg C m^{-3} (Figure 3). Although significant differences between 1975 and 2007-2008 were registered to abundance and body size, these differences were not found to biomass values (M-W, $p = 0.069$).

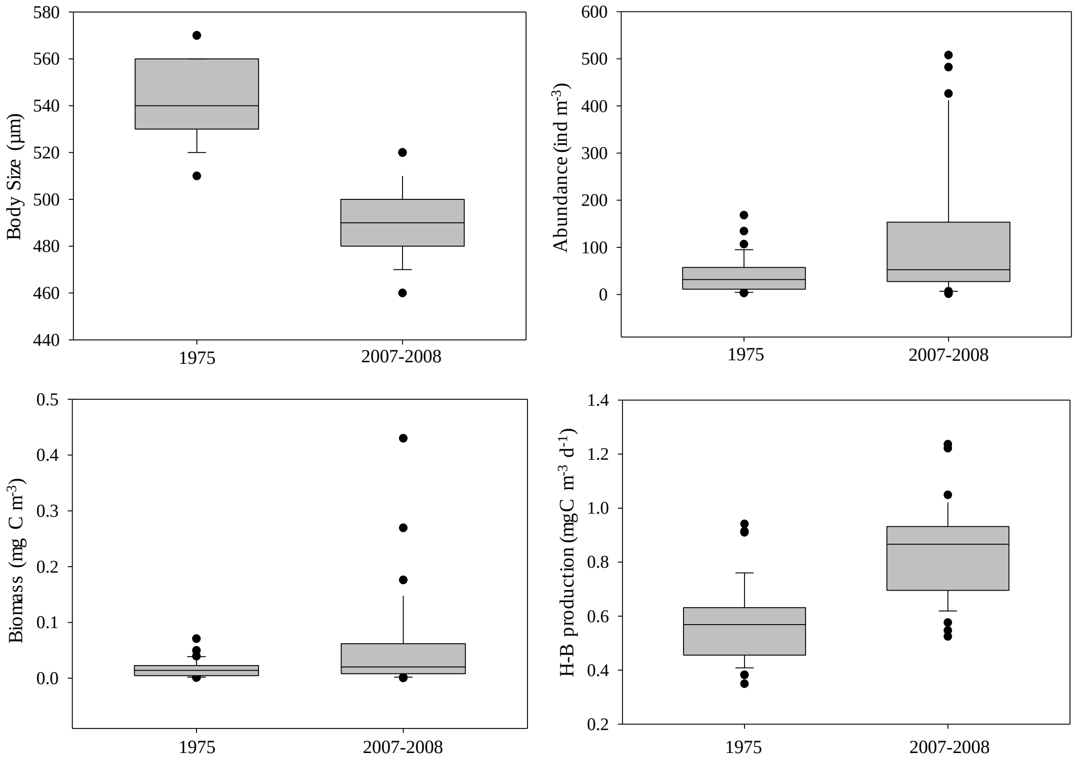
Figure 2 - Environmental parameters (temperature, salinity, dissolved oxygen, transparency, pH, and chlorophyll-a) from Botafogo River estuary in 1975 and 2007-2008.



Fonte: A autora.

The production pattern was of an increase of production from 1975 to 2007-2008. The production in 1975 varied from 0.0005 to 0.0411 mg C m^{-3} d^{-1}, with mean value of 0.0093 ± 0.0089 mg C m^{-3} d^{-1} (Figure 3). The production in 2007-2008 varied from 0.0003 to 0.2784 mgC.$m^{-3}$$d^{-}$1, with mean value of 0.0419 ± 0.0617 mg C m^{-3} d^{-1} (Figure 3). The H-B model presented significant differences between years studied (M-W, $p < 0.001$) with higher production in 2007-2008.

Figure 3 - Biotic parameters (body size, abundance, biomass and H-B production) from Botafogo River estuary in 1975 and 2007-2008.

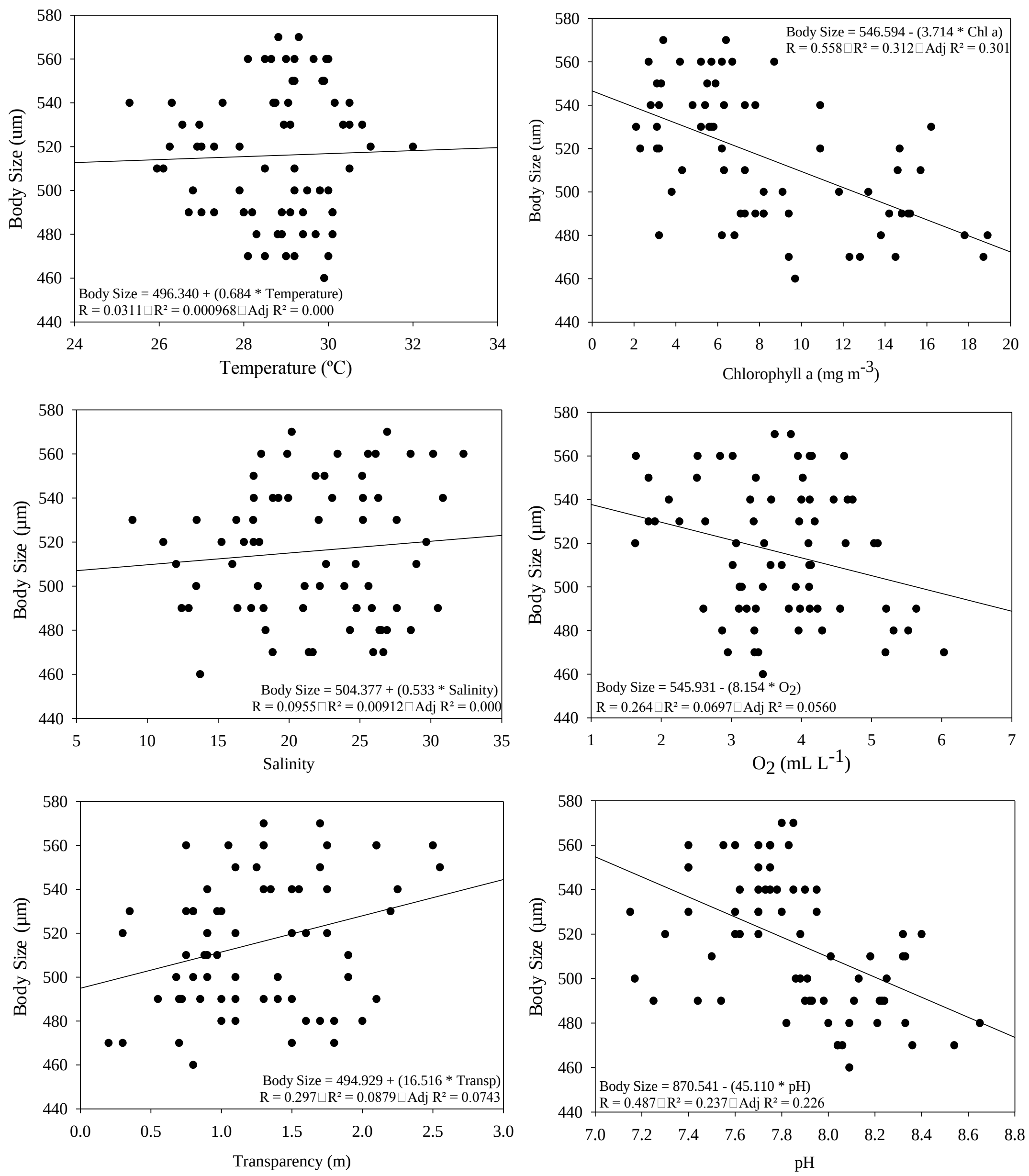


Fonte: A autora.

Regressions and Pearson correlation analysis

The body size was compared with the environmental data to search for possible correlations (Figure 4). There was no evidence of influence neither water temperature nor salinity a significant on the body size ($r = 0.0311$ and $p = 0.798$; $r = 0.0955$ and $p = 0.435$, respectively). Although, chlorophyll-a, dissolved oxygen and pH presented a significant difference and a negative correlation with the body size ($p < 0.0001$ and $r = -0.558$; $p = 0.027$ and $r = -0.264$; $p < 0.0001$ and $r = -0.487$, respectively), while transparency showed significant difference and positive correlation with the body size ($r = 0.297$ and $p = 0.0134$).

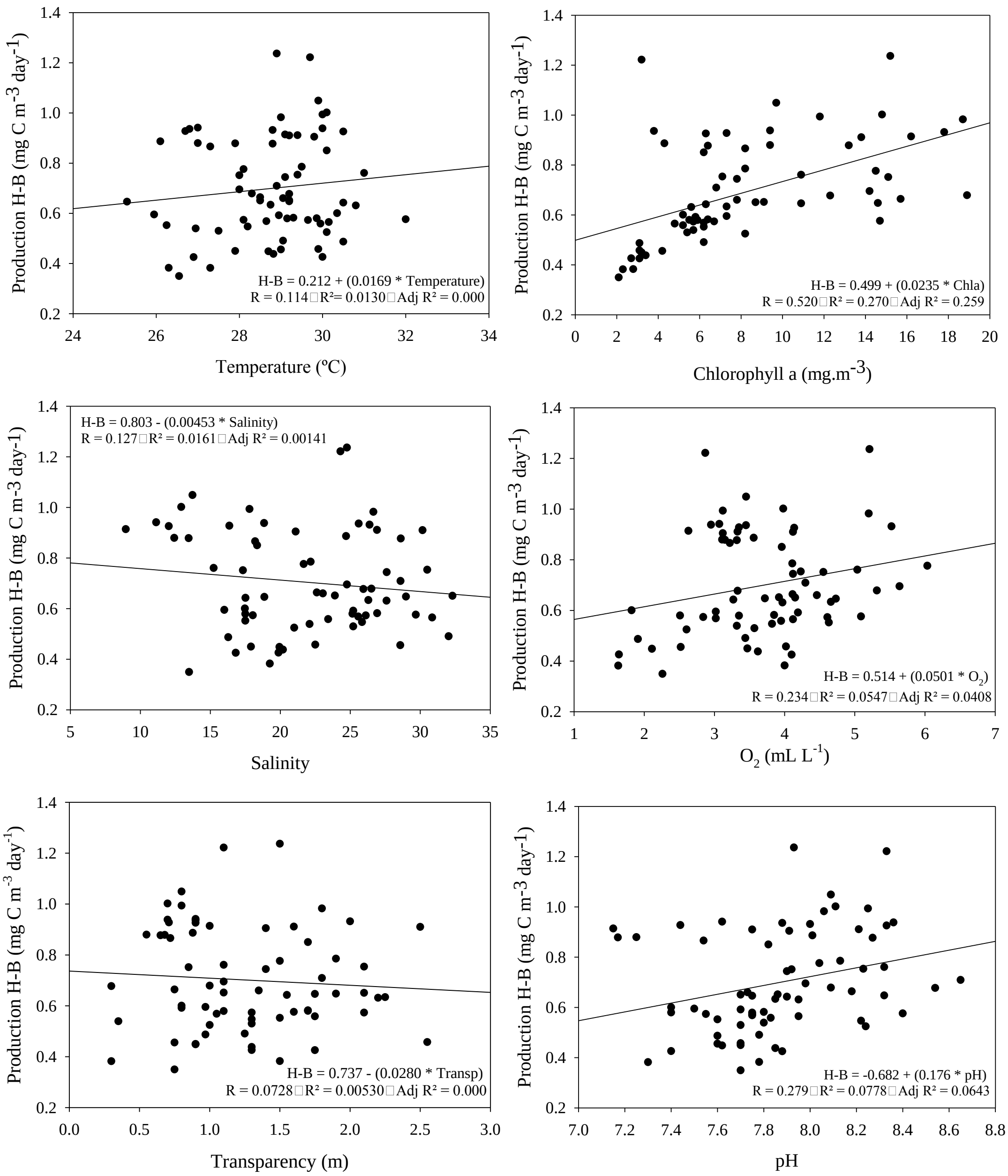
Figure 4 - Simple regressions for Body Size (µm) vs. Temperature (ºC), Chlorophyll-a (mg m^{-3}), Salinity, dissolved O_2 (mL L^{-1}), Transparency (m), and pH.



Fonte: A autora.

The same way as made for the body size, a comparison with the environmental data was performed for the H-B production (Figure 5). Again, water temperature and salinity did not showed an influence on the H-B production ($p = 0.347$ and $r = -0.114$; $p = 0.299$ and $r = -0.127$, respectively), as also the transparency ($p = 0.552$ and $r = -0.0728$). On the other hand, chlorophyll-a, dissolved oxygen saturation and pH presented all a significant difference and a positive correlation with the H-B production ($p < 0.0001$ and $r = 0.520$; $p = 0.00365$ and $r = 0.343$; $p = 0.0193$ and $r = 0.279$).

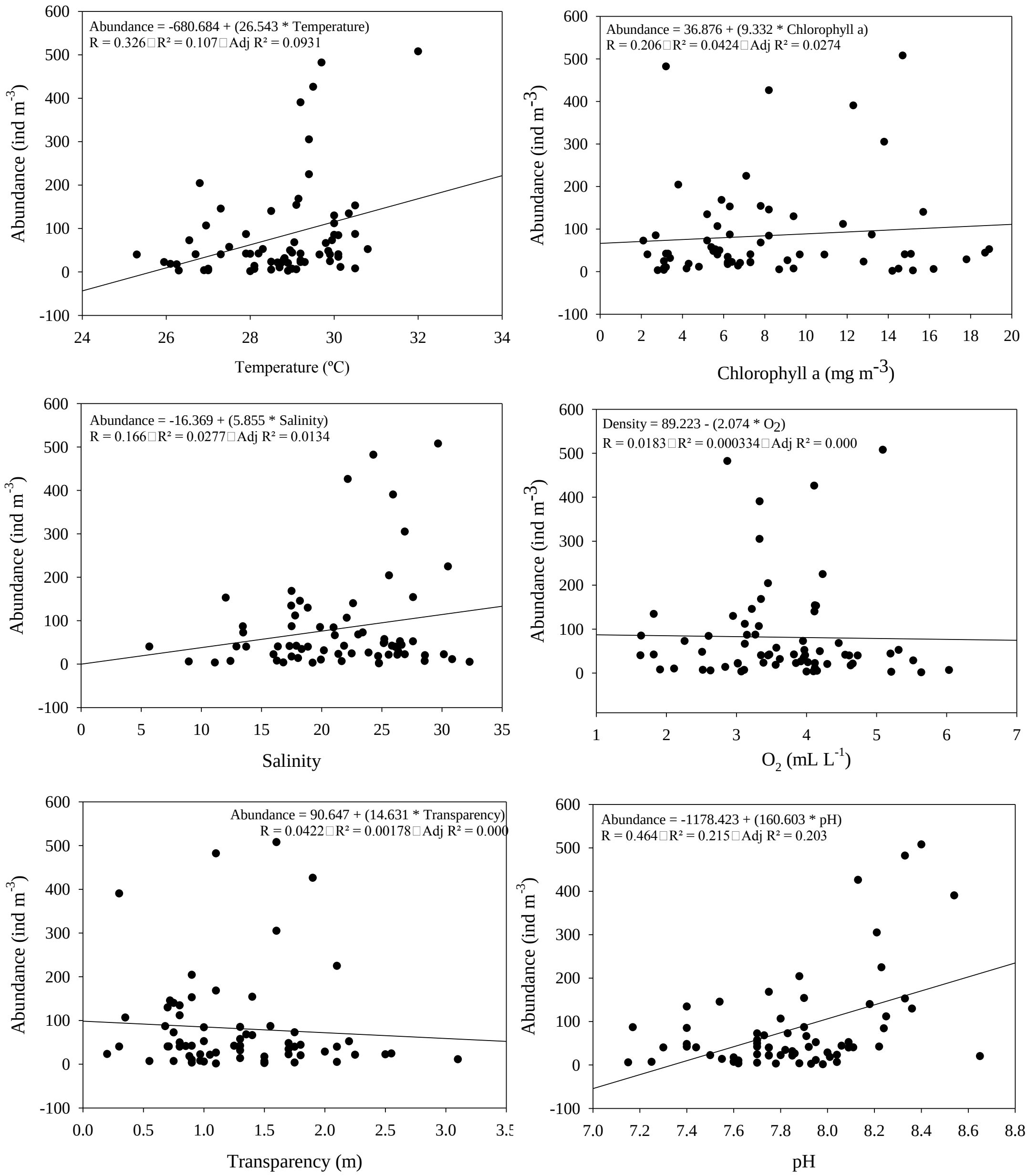
Figure 5 - Simple regressions for H-B Production (mg C m^{-3} day^{-1}) vs. Temperature (ºC), Chlorophyll-a (mg m^{-3}), Salinity, dissolved O_2 (mL L^{-1}), Transparency (m), and pH.



Fonte: A autora.

Searching for correlations, the abundance was also compared to all the environmental data (Figure 6). Among the environmental factors salinity ($p = 0.169$ and $r = 0.166$), dissolved oxygen ($p = 0.882$ and $r = -0.018$), transparency ($p = 0.728$ and $r = 0.042$) and chlorophyll-a ($p = 0.097$ and $r = 0.206$) presented no significant correlations with abundance. Water temperature ($p = 0.007$ and $r = 0.326$) as also pH ($p < 0.001$ and $r = 0.464$) showed significant positive correlations with abundance.

Figure 6 - Simple regressions for Abundance (ind m^{-3}) vs. Temperature (ºC), Chlorophyll-a (mg m^{-3}), Salinity, dissolved O_2 (mL L^{-1}), Transparency (m), and pH.



Fonte: A autora.

DISCUSSION

The Botafogo river estuary is classified by Almeida Prado Por and Lansac Tôha (1984) as an estuary type A, due to the fact that its mouth has no direct contact with the open sea because of the presence of the Santa Cruz Channel, which acts as a sea-arm. This particular feature implied in no significant differences among stations on the analyzed periods, allowing a spatial stability of *Oithona* population on the Botafogo river estuary.

Adults of *Oithona hebes* were extremely frequent and abundant in the 64 micrometers mesh size net both in 1975 and 2007-2008 samples. This species presents a tolerance to salinity and temperature variations, hence its adaptation success in estuarine environments, being one of the most abundant species in the mesozooplankton from many estuarine regions in Brazil (BJÖRNBERG, 1981; PARANAGUÁ et al., 2000) with an important role in the estuarine trophic chain (GALLIENNE; ROBINS, 2001).

The abundance and production of *Oithona hebes* significantly increased from 1975 to 2007-2008 in the Botafogo River estuary. In coastal and estuarine regions with a continuous eutrophication process associated to other anthropogenic stressors, the effect of climate change (mainly temperature) on zooplankton can be difficult to recognize (RICE et al., 2015). Thus, it can be thought that many interrelated factors contributed to the changes found here in *Oithona* population (e.g. climatic changes, organic pollution, nutrients inputs, mangrove deforestation, overfishing, etc.).

The temperature was the main factor influencing positively the abundance of *O. hebes* according to regression analysis and Pearson’s correlation, though water temperature has increased 0.35ºC in three decades. Garzke et al. (2015), using copepods as model organisms to study size responses to temperature in a microcosm experiment, concluded that warming decreased copepod abundance, the opposite found in this study. Studies carried out in Long Island Sound (USA) from 1950-2012 by Rice et al. (2015), proposed that even a small, but constant rise in temperature (even in ecosystems where food is not restrictive) could favor a smaller-sized copepod community, like *O. hebes*.

Then the increase of the water temperature is the first factor that caused changes in the *O. hebes* population on Botafogo river estuary between 1975 and 2007-2008, increasing abundance of this copepod.

In this study, it was found a decrease in the body size between the two studied periods. Since copepods are the main connection between phytoplankton and upper trophic levels, a decrease in the body size could change food web connectivity, reducing the effectiveness of trophic transference between primary producers and larval stages of crustaceans, mollusks and fish (RICE et al., 2015). Although, even with a decrease in *O. hebes* body size, its abundance was higher in 2007-2008 than in 1975. Zervoudaki et al. (2007) showed that the small-sized copepods, like *O. hebes*, had a larger influence on the efficacy of the trophic connection between the phytoplankton and the protozooplankton than the larger copepod species. Then the greater amount of *O. hebes* organisms was enough to enhance the productivity, instead of the body size, maintaining the effectiveness of trophic transference.

Among the environmental parameters studied, the regression analysis and Pearson's correlation pointed out to chlorophyll-a, dissolved oxygen and pH as the main factors influencing body size decrease and a production increase of *Oithona hebes*. In certain temporal/spatial conditions when the temperature has a small amplitude variation (DEEVEY, 1960), as found in the Botafogo river estuary, the phytoplankton concentration, measured here as the chlorophyll-a, becomes the main factor influencing the copepods body size.

An increase in chlorophyll-a (values found in 2007-2008 are almost 100% higher than the ones found in 1975) and in pH (values 0.38 higher in 2007-2008 than in 1975), as saw here, can be interpreted as a main sign of eutrophication in the Botafogo river estuary. Otsuka et al. (2014) studying the environmental parameters (including the chlorophyll-a, dissolved oxygen, nutrients, and pH) in the same stations in Botafogo river estuary and comparing it with previous studies, concluded that the Botafogo river estuary was in a moderate process of eutrophication.

It is well known that the Botafogo river is the most polluted in the Santa Cruz Channel area, presenting visible signs of degradation (CPRH, 1977; BARROS-FRANCA, 1980; ESKINAZI-LEÇA et al., 1984; PASSAVANTE; KOENING, 1984; CPRH, 1999; MELO, 2007). The pollution enters into the area, sometimes in small amounts, at many different locations along the length of the river. Agricultural and shrimp farming along the Botafogo estuary has resulted in higher nutrient (especially nitrogen and phosphorus) and chemical inputs, increasing the eutrophication process (MACÊDO; COSTA, 1978).

Therefore, it can be said that the changes in eutrophic conditions in the Botafogo river estuary are one of the factors that have led to a significant decrease in body size and increase in production of *Oithona hebes* during the analyzed period.

Combined to the eutrophication, the feed ecology of *O. hebes* may have also influenced the abundance and production. The Oithonidae family feed upon Copepod nauplii and motile protozooplankton such as autotrophic and heterotrophic microflagellates, dinoflagellates and ciliates (e.g. NAKAMURA; TURNER, 1997), with the genus *Oithona* efficiently ingesting relatively small particles (CALBET et al. 2000) which can benefit the dominance of these copepods in eutrophic conditions. Almeida and Eskinazi-Sant'anna (2012) found *Oithona* as the dominant genus in an estuarine coastal lagoon in the Rio Grande do Norte (Northeastern Brazil) with high concentrations of nutrients, which makes this genus a potential bioindicator of eutrophic conditions. Also, Uye (1994) suggested that an increase in nutrient output of Tokyo Bay in the 1960s was responsible for a shift in the dominant phytoplankton toward small flagellates, increasing the proportion of *Oithona davisae* in the area. For the Botafogo river estuary, Lacerda et al. (2004) observed a higher abundance of phytoflagellates and a predominance of nanophyplanktonic species.

Therefore, what it was found here is that the eutrophication process, caused mainly by anthropogenic changes, has lead to a shift on the phytoplankton community, with the small flagellates becoming more abundant in the Botafogo river estuary. This shift has led to a change in the zooplanktonic community, and since *Oithona* feeds upon those organisms, an increase in *Oithona* abundance and production was observed.

Overfishing is a known impacting factor in the studied area (BARROS et al., 2000). This impact possible caused changes in the zooplankton community, as fishes compete with jellyfish (in this case, the Ctenophore *Mnimeopsis leidyi*) that increased greatly in the studied estuary (NEUMANN-LEITÃO, personal communication), eating mostly large zooplankton allowing the smaller copepods to increase in number. This behavior was also saw by Uye (1994) in the eutrophic Tokyo Bay.

From all shown here, it is possible to conclude that the Botafogo river estuary is suffering from the global environmental changes, mainly eutrophication and temperature. The eutrophication process is changing the zooplanktonic community in the area: it is enhancing the abundance and production of *Oithona hebes* and reducing its body size. Also, the water temperature is acting to increase the abundance of *Oithona hebes*. It is still uncertain on how this change will affect the whole ecosystem on a long-term basis, being necessary an effort to continue the studies in the area to keep tracking these changes.

4 CONSIDERAÇÕES FINAIS

A presente tese foi desenvolvida com o objetivo de investigar os efeitos das mudanças ambientais globais em espécies chaves de Copepoda no sistema estuarino do Canal de Santa Cruz. A partir dos resultados obtidos aqui, foi possível responder a este e aos outros objetivos específicos propostos. Ainda, foi aceita a hipótese de que "as espécies-chave de Copepoda no sistema estuarino do Canal de Santa Cruz tem sofrido com os efeitos (mudanças nos valores de tamanho corporal, densidade, composição, biomassa e produção) das mudanças ambientais globais".

Primeiramente, a partir do levantamento bibliográfico foi possível constatar que a espécie *Acartia lilljeborgi* e o gênero *Oithona*, incluindo a espécie *Oithona hebes*, se destacavam frente aos outra taxa de Copepoda, sendo muito frequentes e os dois mais dominantes durante o período entre 1970 e 2015. Isto fez com que os dois fossem considerados as espécies-chave de Copepoda da área para os trabalhos seguintes. Ainda, observou-se uma descontinuidade na abordagem, na amostragem e nos estudos como um todo, ressaltando a necessidade da criação de novos projetos de médio e longo prazo para preservar o sistema estuarino do Canal de Santa Cruz e gerar respostas mais concretas para um melhor entendimento e manejo desta área.

Ficou evidenciado, de uma forma geral, que a temperatura e a eutrofização despontam como os principais fatores das mudanças ambientais globais que influenciam as espécies-chave de Copepoda no sistema estuarino do Canal de Santa Cruz.

Para *A. lilljeborgi* e para o gênero *Oithona* como um todo, constatou-se que a temperatura é um dos fatores mais importantes, mas provavelmente não o único, atuando na diminuição do tamanho corporal de *A. lilljeborgi* e no aumento da abundância relativa do gênero *Oithona* em relação aos outros Copepoda. Para a espécie *Oithona hebes*, observou-se que a eutrofização agiu aumentando a produção secundária e diminuindo o tamanho corporal desta espécie, enquanto a temperatura atuou aumentando a densidade.

Os resultados encontrados aqui mostraram que a estrutura da comunidade do sistema estuarino do Canal de Santa Cruz está mudando em direção à uma comunidade dominada por espécies de menor tamanho corporal. Este padrão já foi observado em vários outros locais do mundo e é ocasionado pelas mudanças ambientais globais, principalmente as mudanças na temperatura da água do mar e no processo de eutrofização.

Por fim, esta tese ressalta a importância de estudos de médio e longo prazo para auxiliar na investigação e predição das respostas das comunidades de Copepoda frente às mudanças ambientais globais; assim como trabalhos experimentas para confirmar os resultados encontrados nos trabalhos realizados em campo. Sugere-se aqui, portanto, a criação e manutenção de um sistema de monitoramento contínuo para a área sistema estuarino do Canal de Santa Cruz, área esta que é de, já conhecida, importância biológica e econômica para o Nordeste do Brasil.

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