

## ARTIGO

### Thirty-five years of zooplankton studies in a tropical estuarine ecosystem: what is coming next?

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**ABSTRACT:** Estuarine environments are among the most important ecosystems on the planet because they are extremely productive and act like a refuge to several species. This work presents a synthesis of 35 years of knowledge on zooplankton biodiversity, composition, distribution, abundance and other biological parameters of zooplanktonic organisms from the estuarine system of Santa Cruz Channel (Pernambuco – Brazil). For that, a bibliographic survey was realized, where 52 scientific studies were analyzed. The Copepoda and Decapoda groups were the most studied ones, being the Copepoda well studied during all the 35 years and the Decapoda from the 1990 decade. From all the studies already performed until today, it is possible to affirm that the Santa Cruz Channel is a rich and key coastal ecosystem in the Northeastern of Brazil, being essential the development of new research projects to assist the sustainable management in this area.

**Keywords:** *Acartia lilljeborgi*, bibliographic survey, Copepoda, Decapoda, estuary

### Trinta e cinco anos de estudos do zooplâncton em um sistema estuarino tropical: o que vem pelo futuro?

**RESUMO:** Os ambientes estuarinos estão entre os ecossistemas mais importantes no planeta, pois são extremamente produtivos e servem como abrigo para diversas espécies. Este trabalho apresenta uma síntese de 35 anos de conhecimento acerca da biodiversidade, composição, distribuição, densidade e demais parâmetros biológicos dos organismos zooplancônicos do ecossistema estuarino do Canal de Santa Cruz (Pernambuco, Brasil). Para tanto, foi realizado um levantamento bibliográfico, onde 52 trabalhos científicos foram analisados. Os Copepoda e os Decapoda foram os mais estudados, sendo os Copepoda bem estudados durante todos os 35 anos de levantamento e os Decapoda mais estudados a partir da década 1990. A partir de todos os trabalhos já executados até hoje, é possível afirmar que o CSC é um ecossistema rico e chave no ambiente costeiro do Nordeste do Brasil, sendo essencial o desenvolvimento de novos projetos de pesquisa na área a fim de auxiliar no manejo sustentável deste local.

**Palavras-chave:** *Acartia lilljeborgi*, Copepoda, Decapoda, estuário, levantamento bibliográfico

## 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).

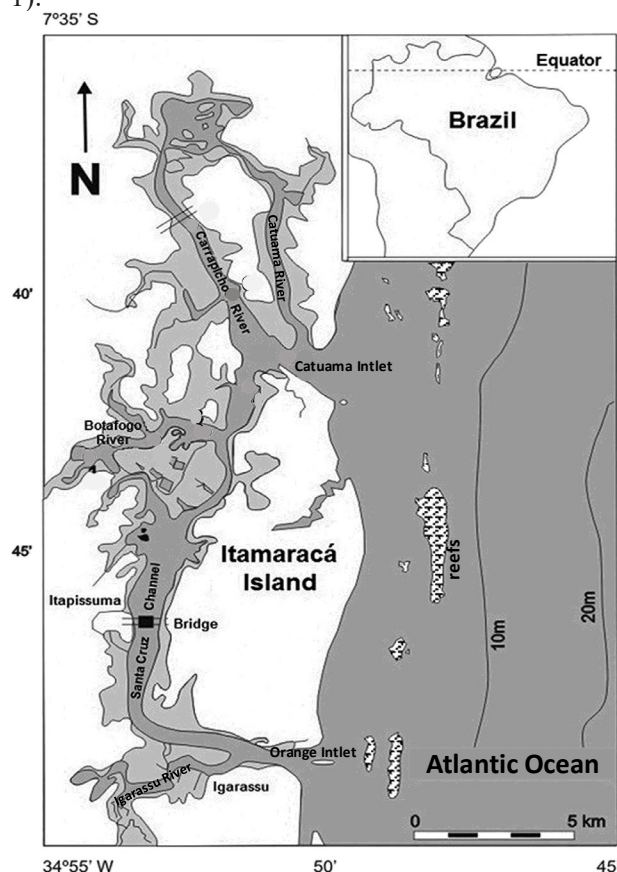
The estuarine system of the Santa Cruz Channel (Pernambuco - Brasil) is considered as one of the most productive in the Northeast of Brazil [with medians greater than 120 t of monthly fisheries landings (NASCIMENTO et al., 2013)], a huge biodiversity and productivity, representing an important environmental 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 7° 34'00" S and 7° 55'16" S latitude and 34°48'48" W and 34°52'24" W longitude (Figure 1).



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

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 Inlet, and to the south, by Orange Inlet. 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 km<sup>2</sup> (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 *Rhizophoramangle* 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 - Pernambuco), 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](http://scielo.org)) and Web of Knowledge (<http://www.wokinfo.com/>) websites, dissertations and thesis (<http://www.bdt.d.ibict.br/>; [http://www.capes.gov.br/servicos/banco-](http://www.capes.gov.br/servicos/banco-ibict.br/)

de-teses; <http://www.teses.usp.br/>; <http://www.dominiopublico.gov.br/pesquisa/pesquisaperiodico>), along with conferences reports and published book chapters.

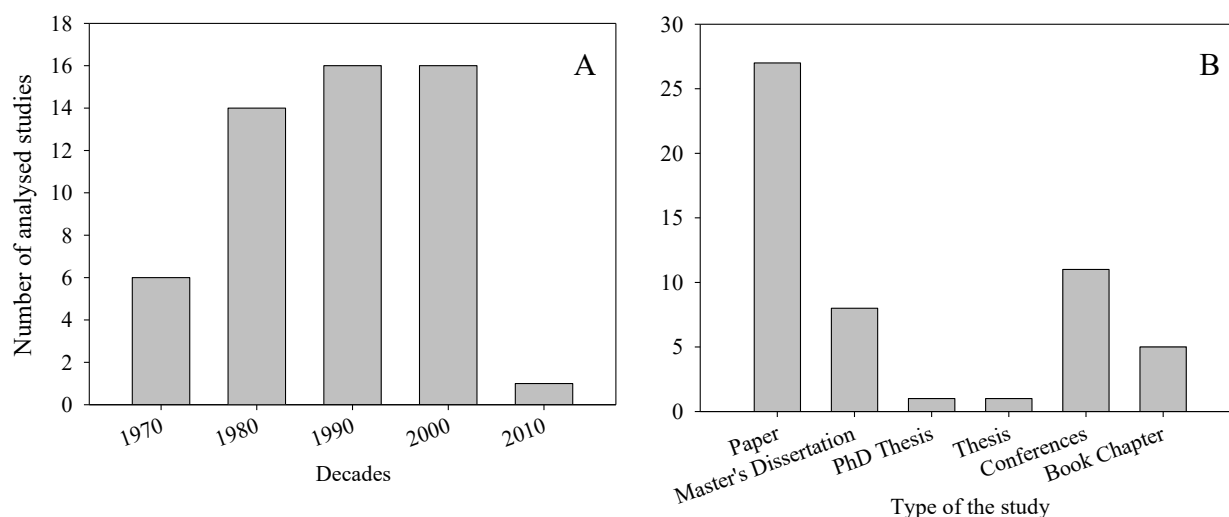
### Initial considerations

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.

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



**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

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  $\mu\text{m}$  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. These 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: Achiridae, 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 (*Cymbaloporeta*

*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 through 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 *Leptotintinnus norqvisti* 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<sup>-3</sup> to 5.201 ind.m<sup>-3</sup>. 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”, Paranaçu 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 system 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 concentrated 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, Grapsidae 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 delimited 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<sup>-1</sup>) 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.

### Conclusions

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 continuous monitoring, with new projects of long-term duration

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