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## Indicators of Environmental Impacts

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# Preface

Imagine the joy of a child innocently playing in the mud. Go ahead, seriously, please take a moment, perhaps close your eyes, breathe easy, and imagine… MUD! Wonderful mud! It is one thing that connects humanity at its greatest innocence. Every child everywhere loves mud! In this moment of our imagining, she is surrounded by an inner and outer world of fantasy, wonder, and beauty. Like a dream, this world is as real to this bright and curious child in that moment, as this world is to you and I in this very moment.

Time passes and now this little girl is all grown up. Among her life's many great accomplishments, she has become a mother, a mentor, an internationally recognized research scholar, and professor of Biological Oceanographic and Paleoclimatology.

I am honored and proud to introduce my best friend and greatest inspiration, Dr. Patricia P.B. Eichler. She, like her own mother before her, is teaching her children and students the wonders of what is really happening in that mud.

So, what is happening down in the marine sediment, and why is it so important? Single-celled microorganisms called Foraminifera live there! Benthic Foraminifera specifically, or "Forams" as they are affectionately referred to. That is what is happening. Forams are so incredibly fascinating and so important that they have become her hobby, career, and life's passion because their many differing species provide insights into our past, present, and future with empirically accurate data.

Not just any data, but climate science data that shows earths preserved geologically impacted change patterns preserved in their shells occurring from millions of years to this moment. Data that reaches over time to help us predict the future! A future where logic and reason shows us that pollution and extinction are not parallel lines, and that eventually these lines will meet; and that timeline appears to be in rapid approach.

Here we hope to impart the wisdom that Foraminiferal ecological data related to abiotic patterns gives us, with their use as stable isotopes for micropaleontology and paleoclimate studies. As cofounders of EcoLogicProject.com our endeavor is to provide accurate data for calibration of the present and past and share these predictable indicators for ocean warming and acidification, as well as sea level rise and loss of biodiversity. We demonstrate how climate change may affect future changes,

which include sea level rise in a warming and acidifying ocean, generating cyclones for example, and including environmental, social, and economic loss. Among the many things we propose, we also wish to make sound recommendations what we hope will "dissuade our collective persistent march toward mass extinction."

Rio Grande do Norte, Brazil — Patrícia Pinheiro Beck Eichler
Boulder Creek, CA, USA — Christofer Paul Barker

# Acknowledgments

The authors are grateful to the Marine Geology and Geophysical and Environmental Monitoring Laboratories (Laboratório de Geologia e Geofísica Marinha e Monitoramento Ambiental Coastal/GGEMMA) and to the Graduate Program in Geology and Geodynamics (PPGG) of the Federal University of Rio Grande do Norte (UFRN).

We very much appreciate the ongoing support of Higher Education Personnel Research Coordination (Coordenadoria de Aperfeiçoamento a Pesquisa de Pessoal de Nível Superior/CAPES) and their many funded projects, starting with Dr. Eichler's master fellowship in 1994, and continuing to the present day. Through the Ocean Sciences Project (Edital Ciências do Mar II N°43/2013, Project N°23038.004320/2014-11), Postdoc Fellowships at UFRN, Brazil, was possible from 2011 to 2016. We also acknowledge the Special Visiting Professor (Professor Visitante Especial) Fellowship (PVE 151/2012 and AUX PE 242/2013) in the Science without Frontiers Program of CAPES, including a laboratory engagement at the University of California Museum of Paleontology in Berkeley and a speaking engagement at the Geology Sciences of Stanford University in Palo Alto California (USA) in 2015. We also thank PROBRAL 337/10 (CAPES/DAAD) for postdoc grants (N° 8116-12-1) at Kiel University in Germany in 2012. This research would not have been possible without the abovementioned funding of CAPES (Ciências do Mar II N°23038.004320/2014-11) and the postdoctoral fellowship grants (N°88887.305531/2018-00, N°88881.188496/2018-01, N°9999.000098/2017-05), at Moss Landing Marine Laboratories at San Jose State University (MLML/SJSU), at the Ocean Sciences Department of the University of California at Santa Cruz (UCSC), and at the International Ocean Discovery Program (IODP) through Texas A&M University (USA) in 2018.

We want to thank the Technical Support to Strengthen National Palaeontology (Apoio Técnico para Fortalecimento da Paleontologia Nacional, Ministério da Ciência e Tecnologia MCTI/National Research Council CNPq N° 23/2011, N° 552976/2011-3) where the "biodiversity of sensible ecosystems in the coastal area of reefs" in northeastern Brazil was studied and verified the possibility of recommending a biodiversity conservation area with practical applicability of science.

The career path success of our chief scientist and lead writer, Professor Eichler, would never have been possible without the incentive and emotional support of Dr. Helenice Vital. She is truly a "vital" person for the marine geology and geophysics of the northeast region of Brazil. Her diligence and accurate research improve and validate the lives of all around her. This includes her students, technical supporters, and many other collaborators, who depend directly upon her for their respective research. She is one of the most competent researchers and scientists of our time and deserves to be honored with humble gratitude and deep appreciation. With her manifold abilities to deal with multidisciplinary research, and to respond accurately to the most adverse situations, she has driven herself and her team to success in many different career paths. These include mentoring geologists, geophysics, geographers, physical, chemical, biological and geological oceanographers, biologists, marine biologists, divers, technicians, engineers, and mathematicians. All of whom have successfully accomplished their own research, studies, and endeavors. She unites people by sharing resources and workload in balanced terms, at the same time gently educating so we all have felt both adequate and a sense of belonging.

We would like to give special acknowledgment to Dr. Moab Praxedes Gomes, also a wonderful mentor, having been influenced by his mentor Dr. Vital, with the understanding that dedication and leadership are values and qualities benefiting both team members and team leaders. Dr. Gomes describes the ocean bottom features with accuracy, curiosity, methodology, and enlightenment that have led us to discover the wonderful world of paleochannels and submerged rivers in the sedimentary and coral reefs of the Rio Grande do Norte state.

Part of the field and laboratory work illustrated in this book from estuaries, bays, and mangroves in the coastal zones of the South, Southwest, and Northeast Brazil was financially supported by the São Paulo State Research Support Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo, Brazil/FAPESP Procs. 96/4191-8; 98/05409-2; 99/10678-5), the Oceanographic Institute of São Paulo University (IOUSP) in Brazil from 1994 to 2004, in the micropaleontology laboratory of Dr. Beatriz Beck Eichler, and the National Research Council (CNPq). Besides field and laboratory work, we are also grateful for the postdoc fellowship from the Delaware Geological Survey (DGS) and from the College of Marine Studies (CMS) of the University of Delaware from 2004 to 2009, which provided the understanding of marine stable isotopes and hypoxia and acidification in coastal environments specially enclosed Bays.

Thank you to João Pildervasser of Life Sciences of Springer Nature. His well-mannered approach, knowledgeable research specific to "Foraminifera," and understanding of scientific papers brought Dr. Eichler this invitation to share this work—a wonderful subject that has been the focus of her career and research, as well as that of her own mother before her.

As an international research biologist, oceanographer, and lifelong dedicated ecologist, Patricia is deeply concerned about the collective human impact effects to our beautiful planet. In her words: "I am deeply grateful to Christofer Paul Barker and the opportunity to co-promote the EcoLogicProject ideal". Our shared vision is to illuminate the message of eco-stewardship and preservation through environmen-

tal sustainability. Like myself, Christofer has dedicated his life to this endeavor. His love for the environment, and all life, has brought him to discover the scientific "y" side of his observations and correlations, including research on biodiversity and sustainability to preserve and conserve nature now and for future generations. For these and many reasons, I have invited Chris to coauthor this book, as we further our collaboration in bringing the message that a better world will exist when people with similar environmental ideals and interests unite for "the preservation of the environment and its biodiversity in its prime stage." Chris says; "he could not have said it any better describing Dr. Eichler, or in reciprocation of appreciation, for her meteoric knowledge and understanding, kindness, patience, wisdom and tireless dedication."

"My reason to exist," says Patricia, "are my daughters Maria Gabriela and Anna Julia, which my life is dedicated to. They show me that patient guidance and love results in a formula for success. I hope to share this message so that others also prioritize responsibility for sustaining and preserving a world that will support their lives, and their children's lives. For that, above all, I am thankful for the teachings and example that I receive from my own parents every day. Bea a loving naturalist and Otto a brilliant engineer. Both have dedicated their lives to improve my life and the lives of all around us. With the example of love and care, they have taught me to look upward and work for a better future, to live in the present, and learn from the past."

Lastly and perhaps, most importantly we both wish to thank the reader for doing the work and taking the steps to preserve, conserve, and connect with nature. It is that connection that roots us firmly in the tree of life, as part of, not apart from, Mother Nature and her infinite bounty that supports and sustains all life.

EcoLogicProject.com

Patrícia Pinheiro Beck Eichler Christofer Paul Barker

# Introduction

We will show you how Benthic Foraminifera are the most powerful climate and ecology tool that scientists can use as environmental indicators. They are the "First Responder Indicator Species" and are readily found in marine sediments worldwide showing us geomorphology which identify potential problems.

Research and academia often operate under the constant pressure of ongoing high-dollar perpetual funding. Other added bonuses that Forams provide are that they are an accessible, inexpensive, easy-to-handle proxy of gargantuan statistical significance.

These "tiny giants of the great seas" earn that title in humble yet esteemed scholarly research circles. The microscopic shells of these creatures are made of calcium carbonate ($CaCO_3$) and the marine sediment layers provide us with information of what has been happening with the carbon record over time. Each widely distributed specific Foraminiferal indicator species differentiates particular habitats (and geohabitats) from deep oceans to brackish lagoons, estuaries, and even freshwater. Fossils from these tiny Foraminifera yield clues about past climates.

As "the first responders" these plentiful unicellular microorganisms react rapidly to the slightest environmental changes. Their shells carry a record of these alterations, showing the absolute environmental condition of habitats and ecosystems that the creature lives in at the moment of its sampling. Because their shells also fossilize, they show us an accurate historical record pattern into paleo ecosystem conditions. This makes it possible to accurately identify climate and condition patterns from millions of years past up to our own unfolding recent environmental patterns.

To quantitatively measure environmental impacts, foraminiferal communities' dynamics are used simply because their rapid response to change is so graphic that it is easy to read. Abundances of key foraminiferal species generate comparable index values temporally or spatially. Besides the value of being distributed globally on land and in virtually all marine sediments, foraminifera provide yet another benefit as a model of "calcifying symbiosis" for testing stressors that threaten the ecological integrity of coral reef ecosystems. Data on benthic foraminiferal absolute and relative abundances or indices from marine sediment are applied worldwide to quantify changes in benthic ecosystems under natural and anthropogenic influences.

Benthic foraminiferal communities' dynamics as environmental impact indicators effectively identify and classify patterns, as well as differentiating natural processes, or those caused by human interference. Their distribution pattern applicability, in different kinds of environments on coasts all over the world, from pristine undisturbed natural environments, to heavily polluted and/or contaminated effluents, helps researchers identify problems and provide recommendations for mitigation and remediation solutions.

A considerable part of the beauty, accuracy, and simplicity of foraminiferal research is that although we need academic scholars and their interpretations, a great deal of this research simply requires minimal technology applied by technicians with modest training. Moreover, there is even ample near-future opportunity to implement artificial intelligence should academia feel the need for more expensive and even faster techniques.

# Contents

# About the Authors

**Patrícia Pinheiro Beck Eichler** Our Chief Scientist, Academic Advisor, and Cofounder Professor Eichler is a multi-linguist and mentors undergraduate, master's, and PhD students at private and public universities and schools internationally. She gives students a positive and welcoming experience to help them thrive in their science training. This includes the opportunity to boost their careers as coauthors within her extensive publications including journals, articles, press releases, etc.

Professor Eichler is among the world's foremost scientists in the biological oceanographic environment, with specialized experience in coastal processes, communities dynamics, sediment transport, and estuarine dynamics.

**Christofer Paul Barker** Cofounder and Operations Coordinator, Christofer is passionate about EcoLogicProject's mentorship and consultancy ability to accurately forecast climate change effects and provide disaster mitigation and remediation solutions. His dedication to environmental sustainability and vision of bringing fact-based climate science forward have coalesced into collaboration with Dr. Patricia Eichler and her international oceanic climatological research. Land-ocean-atmosphere interactions and mechanisms research allows him to also contribute as editor in numerous science publications and provide scientific technical support for the public, students, and client's services and needs.

His consultancy services include eco-stewardship solutions for viable sustainable nontoxic alternatives, leading to The EcoLogicProject Partnership.

# Chapter 1
# Playing in the Mud: Benthic Foraminiferal Communities—Dynamic Environmental Impact Indicators


**Abstract** We show the applicability of the use of foraminifera communities dynamics correlated with abiotic parameters to provide data in environmental quality and coastal management plans. In this sense, we pinpoint sites most subjected to pollution and contamination and we identify differentiate effluents even when salinity and temperature values form gradient. Foraminiferal assemblages show increase in abundance of tolerant species to specific abiotic parameters. Density and diversity negatively correlated with heavy metal and PAHs. Increase in percentages of deformed or abnormal organisms and reduced size of the organism when they are exposed to heavy pollution mainly due to Hg, PAHs, and PCBs. It was observed that tolerant opportunistic species (*Ammonia tepida* and *Buliminella elegantissima*) benefit directly from organic contamination increasing their relative abundance. The other type of benefit may be indirect, as has occurred for *Elphidium* spp., which greatly increases its dominance due to the absence of other species that have had their shells dissolved first, resulting primarily from the impact of the oil spills. On the sedimentary and coral reef areas, *Amphistegina gibbosa* tests were not found at sites where reefs are walked upon. The presence of hard substrates and coarse sediment, rather than water depth, seems to be controlling the distribution of the tests. The results to date reaffirm the use of foraminiferal species in studies of oil spills, contamination by sewage, and industrial pollution even where the dissolution of carbonate is active due to low pH values. We then conclude that pollution or contamination of an environment overlaps the "natural" zonation and gradient of environmental factors, therefore limiting the establishment of species that are strategists and not opportunists.

**Keywords** Pollution · Contamination · Foraminifera · Thecamoebian · Opportunists · Strategists · Abiotic environments · Interface sediment-water



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## Introduction

Our goal is to provide readable reliable accurate information, for anyone to understand, about environmental factors that influence patterns of benthic foraminiferal distribution in transitional and marine ecosystems. In addition, we intend to identify patterns or potential problems now or that may arise in the near future, and to make sound recommendations toward sustainable 'eco-stewardship' for people to act upon, adapt, and make necessary mitigation and remediation changes.

Benthic foraminifera are environmental bio-indicators, especially in polluted and contaminated environments where their sensitivity to stressors are expressed by their assemblages, to alterations of the communities' dynamics. Their distribution patterns in ecological bio indicator pathway studies show up as early as 1959, with Zalesny studying the Santa Monica Bay in California, USA. He stated that 'environmental factors such as currents activity, nutrients, salinity, characteristics of bottom sediments, and especially temperature should control the distribution patterns of the living benthic species in that bay. Since then several works have focused on the effects of various types and sources of pollution in different marginal habitats (Setty and Nigam 1982; Sharifi et al. 1991, Alve 1991, 1995). The number of these kind of studies has significantly increased according to an extensive review of research over the last decade about Foraminifera as bio-indicators of pollution (Suokhrie et al. 2017).

## *What "the Hell on Earth" Is Going On?*

The problem is human; more accurately, the attenuating western colonization lifestyle model, where greed trumps reason and accountability, and our 'anthropic' activity has caused negative impact effects worldwide, for the post-industrial age, and also for the millennia!

Industrialization contaminants and pollutants increase from domestic or industrial sources are discharged daily, into our air, land, coastal areas and oceans. This measurable increase has accelerated greatly since the early 1960s. Humans in mass are out of touch with 'living as caretakers gently integrated with nature'. Global pollution from industries and domestic contaminations negatively affect everything that sustains life—water, air and soil.

The planet earth, our mother-earth-nature, literally provides everything we need to thrive. The pursuit for "more stuff", power, and of course money, while polluting our life-source is illogical and unsustainable. The effects not only pose human health threats, but also initiate eventual mass extinction of many other species, including our own. Our eco-stewardship is to protect the source of life, not abuse it. Otherwise, we will leave our children and the following generations cesspools of toxic and acidic wastewater—or worse. At some point, somewhere, we all came from "indigenous people". Indigenous people have always sustainably protected

natural resources, looking ahead for seven generations into perpetuity. The reason why we are all here now, it is because indigenous people have always done this.

Persistent pollutants like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, heavy metals and others have a particularly deleterious effect everywhere, including to aquatic life. Organic matter contamination and accumulation from domestic runoff is another problem. Large amounts of untreated sewage also flow directly into lakes, rivers, bays, estuaries, mangroves and oceans worldwide. Untreated sewage carries virus and bacteria, which transmit deadly diseases such as cholera, hepatitis and the new deadly coronaviruses. Unfortunately, the sewage effluents often will deposit closer to our houses, and yet we may only experience the damaging effects much later on. Large amounts of organic matter dumped in coastal areas also cause algae 'blooms' proliferating and releasing toxins that kill aquatic life. The environment suffers from oxygen depletion from fast algae blooms, and saline and fresh water mass density differences with high stratification can also enhance stagnation, preventing mixing of water of different densities, worsening effects. Pollutants and contaminants enter the food chain as well, and the effect on the "first responders and consumers" shows up reaching the highest trophic levels.

## *What Are We Going to Do?*

The solution, in part, is to identify natural from anthropogenic patterns, and reverse the effects of environmentally negative human activity. This sounds easy but it is not. This profoundly complex problem can, however, literally be solved with a very simple approach.

We need to use the conditioning and programming effects that education, media, and religion already provide, to use these media channels, to reconnect humanity with Mother Nature the source of our life, and with our eco-stewardship. It is that simple! From home to kindergarten, all the way through higher education and beyond, we can use curriculum, theocracy, and multimedia to influence everyone.

Through the cooperation of international private and intergovernmental multimedia and religious-leadership, we can influence each other to create a better narrative. One that provides solutions oriented messages, and to promote awareness, self response-ability, volunteerism, accountability, and actions that sustain, preserve and maintain our ecology.

In the meantime, at least some definitive answers and solutions for coastal and marine environments are found right now through researching simple microorganisms in mud. After all, they are the first consumers at the lowest level of the food chain, and the first to respond showing positive or negative effects in the ecological chain of "natural" or "disturbed" environments!!

## *How Are We Going to Do It?*

Good question… Well, we are doing our best to inspire everyone to do their best. This includes creating resources and services that optimize our EcoLogicProject message, encourage participation, and influence positive outcomes.

Foraminifera are inexpensive easy-to-handle environmental indicator solutions. They help us identify contamination and pollution sources. They help us rapidly summarize environmental characteristics on and offshore. They highlight environmental variations over short periods, with sensitive reactions to seasonal changes and 'anthropogenic' effects. In addition, another great advantage is their abundance and our ability to easily collect them.

Some Forams species respond favorably to pollution and become dominant in contaminated areas, while others react negatively, decreasing in size, or becoming absent. In polluted areas, benthic Forams usually decrease in diversity until only one single opportunistic species remains.

Globally foraminifera establish themselves in natural, polluted and contaminated conditions, giving us the 'clues to the scene of the crime', 'who done it', and 'how to solve the case'.

Brazil is a prime example for at-risk environmental 'crimes-against-nature' conditions with mounting crisis looming. Our studies here show areas experiencing hazardous pollution or contamination. Forams clearly show us these problems, and target the offending sources, which allows us to highlight solutions.

Here in this first chapter, our intensive case study focus has stretched over 2400 miles (3870 km) along the coast from Laguna in the south, north up past Rio de Janeiro and Bahia, ending at Natal. We are looking specifically in semi-enclosed lagoons, bays, estuarine channel systems, and coral reefs where Forams unravel the environmental issues these coastal areas have.

Below we see first responses that foraminiferal associations have to different ecosystems. We show problems and information about geomorphology and indicator species, and provide recommendations to dissuade the persistent "collective march" toward mass extinction in this our Anthropocene era within these wet systems.

## *Laguna, Santa Catarina: A Semi Enclosed Coastal Lagoon (with the World's Only Wild Dolphins That Cooperatively Help Humans Catch Fish!)*

Located 130 km south of Florianópolis (capital of Santa Catarina state) are three interconnected lagoons: Santo Antônio, Imaruí and Mirim, which are about 40 km long. We started with 25 biological and geological samples at the entrance of the lagoons near Laguna city, followed by sampling inside these lagoons, until reaching the entrance of D'Una River (Imbituba city) (Fig. 1.1).

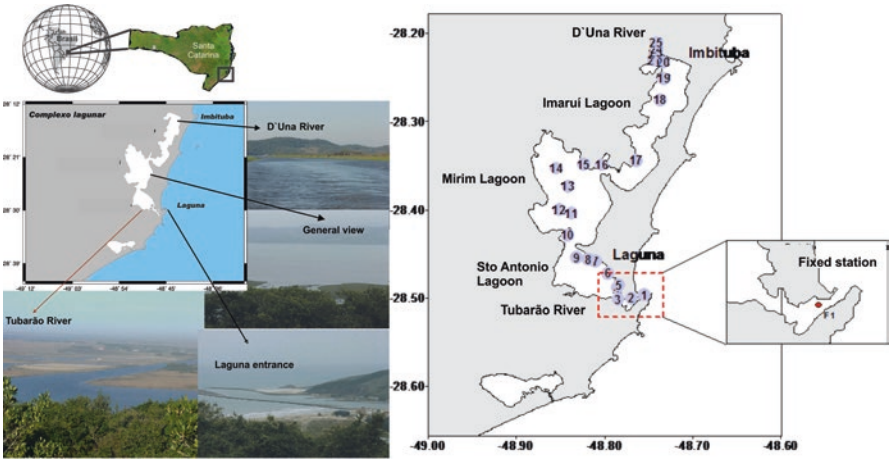


**Fig. 1.1** (**a**) Study area. (**b**) Marine sediment samples and measurements of hydrographic properties with samples collected in summer and winter and fixed samples (F1) in summer

This lagoonal system is characterized by elliptical cells connected to the adjacent ocean by a single narrow channel, which allows classifying it as suffocated. They are mesotidal lagoons with high-energy gravity waves. The channel acts as a dynamic filter, and consequently effects of tidal and current oscillation are attenuated inside the lagoon.

This type of lagoon has large fluvial discharge times, dominant wind effect, and intermittent variation of vertical stratification due to solar heating and freshwater discharge (Miranda et al. 2002). There are marsh grasses on the lagoons' margins, and this area is the southern limit of mangrove occurrence in Brazil. The risk potential in this area deals with the chemical industry to the north of the lagoon close to D'Una River, the use of illegal mesh in nets for fishing, and site constructions to the south close to Tubarão River. Close to urban areas of Imbituba and Laguna, there are untreated domestic sewage and contaminating aquaculture dumping practices in places where Bottlenose Dolphins (*Tursiops truncatus*) live and have an interspecies cooperative interaction with fishermen. However these amazing dolphins are slowly going extinct in part because of illegal mesh fishing net ('ghost nets') practices that are threatening their populations.

Our salinity and temperature study in these lagoons revealed colder temperatures in the bottom waters when values are compared to the surface waters, and salinity variation is intense in winter (Fig. 1.2a, b).

Descriptive univariate data show decrease of biodiversity revealed by the total number of benthic foraminiferal species toward inner parts of the lagoons. Moreover, in a clear type of zonation, their shells features are a response to the "natural" salinity and temperature gradient in the environment provided by the interface sediment-water where they live. Forams shells can be calcareous (made of $CaCO_3$) occurring in the entrance of the lagoon, and agglutinated (attaching sediment grains to its shell) occurring towards middle and inner part of the lagoons (Fig. 1.3a, b).

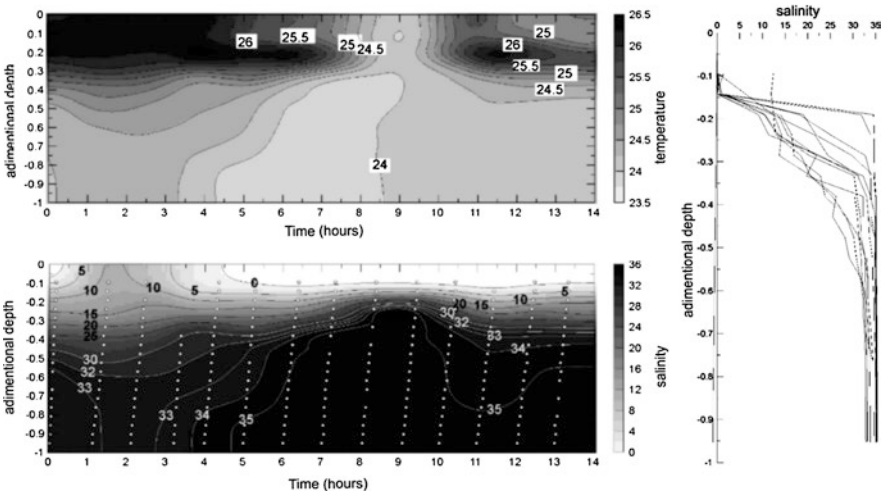


**Fig. 1.2** (**a**) Temperature and salinity in the fixed station. (**b**) Vertical salinity profile in the fixed station

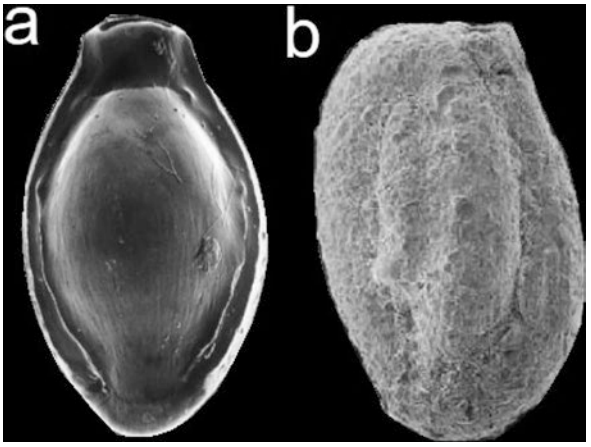


**Fig. 1.3** Basic differentiation of shells ((**a**) Calcareous; (**b**) Agglutinated)

Besides descriptive univariate analysis in biological data to verify biodiversity, we also applied a multivariate approach in abiotic data using Principal Component Analysis (PCA) and a Multi-Dimensional Scaling (MDS) in the biological data. PCA was applied to the abiotic data matrix in winter and summer to explain the variability of lagoons' samples. PCA (Fig. 1.4a, b) shows that summer **(AV, CV, DV, BV)** and winter groups **(AI, BI, CI, DI)** are similar and respond to similar abiotic parameters (depth, $CaCO_3$, temperature, salinity, oxygen, surface pH, granules, sand, silt, clay, and organic matter).

MDS in matrix of summer biological data show formation of four groups (Fig. 1.5a), and winter biological data shows samples presenting two groups

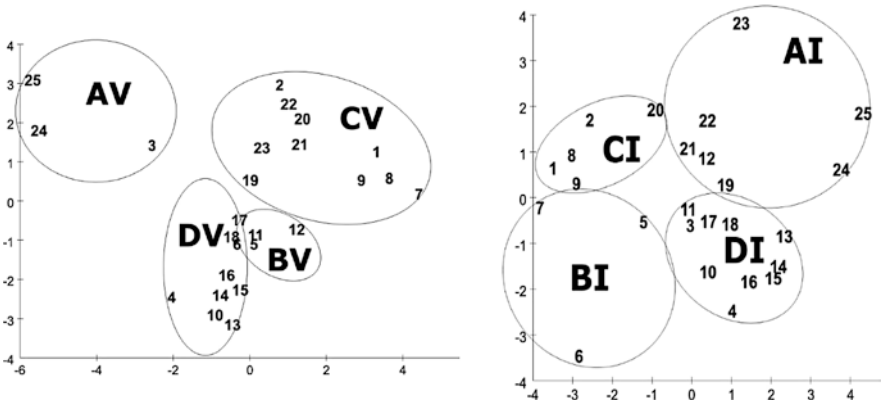


**Fig. 1.4** (**a**) PCA in the matrix of hydrographic and sedimentological data of summer (where AV: depth; BV: temperature, salinity, surface and bottom oxygen and superficial pH; CV: deep pH, granules and sand; DV: silt, clay, organic matter and $CaCO_3$). (**b**) PCA in the matrix of hydrographic and sedimentological data of winter (where AI: depth and $CaCO_3$; BI: temperature, salinity, oxygen, superficial, and bottom pH, and granules; IC: sand; DI: silt, clay, organic matter)

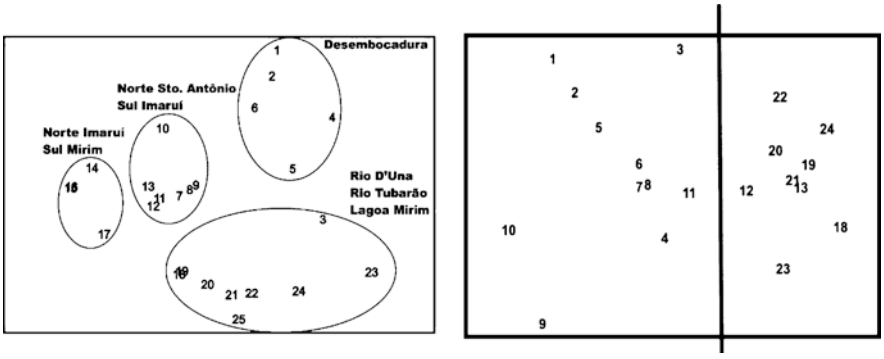


**Fig. 1.5** (**a**, **b**) MDS analysis in the biological data matrix in summer and winter

(Fig. 1.5b). This setting also show similar samples in relation to salinity and temperature zonation.

This salinity and temperature gradient is remarkable and foraminiferal communities derived from it can be observed in Fig. 1.6 where a zonation map with main dominant foraminiferal and thecamoebians (microorganisms indicative of higher freshwater input) species are distributed along a salinity/temperature gradient.

Foraminiferal associations present well-defined spatial distribution and zonation resulting from environmental conditions established due to seasonality and tidal influence of continental input and marine waters. Near the ocean, succession of marine influence and mixohaline environments present calcareous species (*Quinqueloculina* spp. 19–21; *Saccamina sphaera* 18; *Cassidulina subglobosa* 17; *Pseudononion atlanticum* 16; *Buliminella elegantissima* 15; *Bolivina striatula* 14;

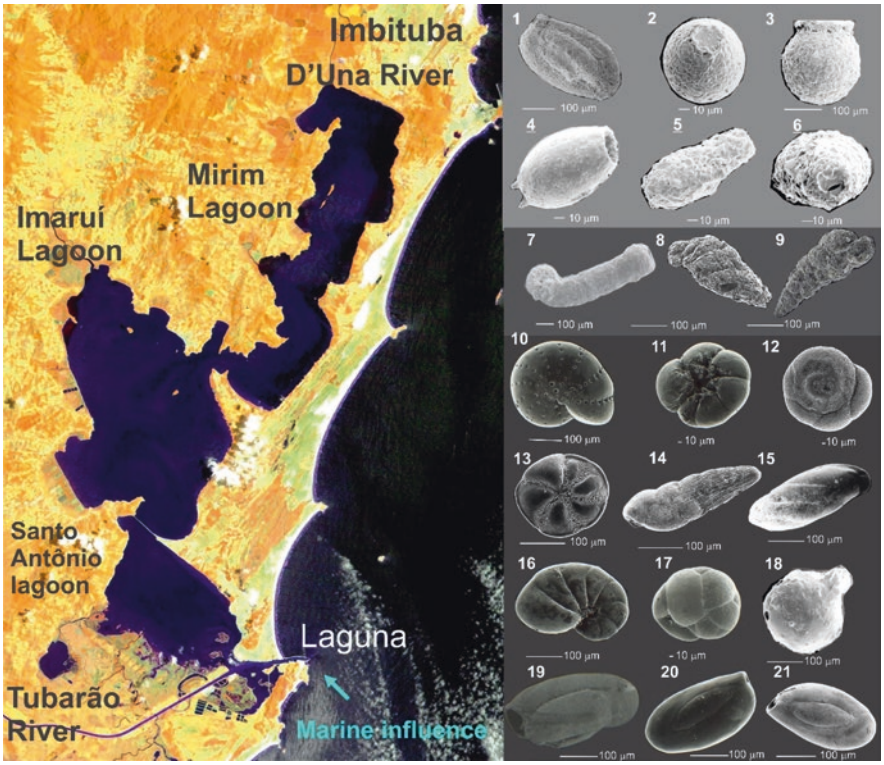


**Fig. 1.6** Zonation map with main dominant foraminiferal and thecamoebians species

*Buccella peruviana* 13; *Ammonia* spp. 12; 11; *Elphidium poeyanum* 10). Mixohaline environments with calcareous and agglutinated species (*Gaudryina exillis* 9; *Ammotium salsum* 8*; Ammobaculites exigus 7*) in the central part. In the northern part of the lagoons, where fresh water input is more intense, the agglutinated *Miliammina fusca* (1) and thecamoebians: *Pontigulasia compressa* (6), *Difflugia capreolata* (5)*, Centropyxis aculeate* (4), and *Difflugia oblonga* (3, 2) are indicative of higher freshwater input.

This significant horizontal gradient observed along the lagoons is the result of balance between the periodic intrusions of saline waters into the system by tide and fresh water input from Tubarão and D'Una rivers. Those two rivers are important because of the urbanization of the cities of Tubarão, Laguna and Imbituba in the state of Santa Catarina, Brazil. Tubarão River banks have coal and thermal power plants, and D'Una River waters contain waste from rice monoculture entering the water flow daily. Tubarão River is located closer to the entrance and is more subject to the renewal of its waters by the ocean. The D'Una River is located very far from the ocean and its waters are not benefited with the renewal of ocean waters. Moreover, due to the higher depth of this river (5 and 7 m) in relation to the lagoon