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# Introduction to the Special Issue on Climate Change and Brazilian Coastal Zone

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**Abstract.** The multidisciplinary Coastal Zone (CZ) network from the National Institute of Sciences and Technology (INCT) for Climate Change, aims to evaluate the state of knowledge and coordinate projects dealing with the effects of global climate changes in the country's coastal zone. During its first year, CZ focused on literature review, historic data analysis and vulnerability studies. The studies were presented during the ***I Brazilian Workshop on Climate Change and Coastal Zones***, and resulted in the fifteen scientific articles that comprise this Special Issue. Based on regional case studies and a few broad national assessments, results showed how the large Brazilian coast and their ecosystems are highly vulnerable to climate variability, and which parameters and regions may be more impacted by global climate change. With only a few studies aiming to evaluate the vulnerability of biological, ecological and socio-economic parameters, along with the many deficiencies on basic knowledge, the country's coastal and marine zones are still neglected by climate change policies. Although a series of scientific goals still need to be achieved to better evaluate the effects of climate change on the Brazilian coastal zone, the present volume constitute a first step towards the provision of guidance to managers and policymakers.

**Key-words:** Global Climate Change, impacts and vulnerability, oceanography, coastal geology, marine ecology.

**Resumo. Introdução ao Volume Especial sobre "Mudança Climática e Zona Costeira Brasileira"**. A rede Zona Costeira do INCT para Mudanças Climáticas, de caráter multidisciplinar e interinstitucional, objetiva de avaliar o estado do conhecimento e coordenar projetos que investiguem os efeitos das mudanças climáticas em zonas costeiras brasileiras. Em seu primeiro ano, os projetos focaram em revisões da literatura, análises de banco de dados e sobre vulnerabilidades dos ecossistemas. Os resultados foram apresentados durante o ***I Workshop Brasileiro de Mudanças Climáticas em Zonas Costeiras***, resultando também nos 15 artigos deste Volume Especial. Tendo como base estudos de caso regionalizados e algumas avaliações nacionais, os resultados mostram como a extensa costa Brasileira e seus ecossistemas são altamente vulneráveis a variabilidade climática, e quais parâmetros e regiões poderão ser mais impactados pelas mudanças climáticas globais. Com poucos estudos específicos que avaliem a vulnerabilidade de parâmetros biológicos, ecológicos e socio-econômicos, associado às inúmeras deficiências de conhecimento básico, as zonas costeira e marinha brasileiras são ainda negligencias pelas políticas de mudanças climáticas. Ainda que uma série de metas científicas necessite ser alcançadas para melhor avaliar os efeitos das mudanças climáticas em zonas costeiras brasileiras, os artigos apresentados neste volume constituem passos preliminares para guiar a gestão e a elaboração de políticas públicas sobre o tema.

**Palavras-chave:** Mudança Climática Global, impactos, vulnerabilidade, geologia costeira, ecologia marinha.

## Introduction

Global Climate Change (GCC) has been at the centre of scientific debate during the 21st century and has received substantial attention from society, governments and the private sector worldwide. Despite active debate and recognized climate uncertainties, the scientific evidences for global warming remains robust and the conclusion that human activities are affecting the climate cannot be undermined (*e.g.* Schiermeier 2010). Indeed, evidences from hundreds of studies are suggesting that the pace and scale of changes and its impacts are surpassing the predictions outlined by the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007) (McMullen & Jabbour 2009, Hoegh-Guldberg & Bruno 2010, Nicholls *et al.* 2010, Stroeve *et al.* 2011). Global Climate Change (GCC) is recognized now as a planetary crisis, which impacts represent an unprecedented risk for natural ecosystems and human civilization.

Because coastal areas are directly affected by sea-level rise, increases in air and sea temperature, exposure to extreme events and ocean acidification, these areas will be impacted most severely by the predicted GCC (Trenberth *et al.* 2007). However, despite the significance of the climate-related risks affecting the low-lying habitats, the paucity of scientific publications dealing with specific and regional problems is remarkable (Nicholls 2007) and coastal and marine systems are vastly underrepresented in comparison with terrestrial systems (Richardson & Poloczanska 2008, Hoegh-Guldberg & Bruno 2010). Studies and predictions relating to the impacts of climate change on coastal and marine ecosystems are limited by the lack of long-term data, by the lower observational capacity and by a lack of integrated approaches to link diverse aspects of science and society. The lack of information at the regional and local scales produces uncertainties about climate, and these uncertainties hamper efforts to plan for the future (Malone *et al.* 2010). Furthermore, no coastal and marine region on earth is exempt from anthropogenic modifications and impacts that affect the ecosystem equilibrium and capacity to buffer climate change (Halpern *et al.* 2008).

Brazil is a globally important country in the context of climate change. Owing largely to its historical deforestation rate, the country is the world's fourth-largest greenhouse-gas emitter (Nepstad *et al.* 2011). Moreover, Brazil depends strongly on its very abundant natural resources. Because of that, the country has therefore great potential to contribute to the reduction of GCC risks. Most of the discussion about Brazil's contribution to mitigate global climate (Santili *et al.* 2005), as well as studies about impacts and vulnerability of natural ecosystems to climate change, has been focussed on terrestrial ecosystems (e.g., Salazar *et al.* 2007, Lapola *et al.* 2009). However, the country's large coastal and marine zones as well as the country's role in buffering climate change impacts and mitigating emissions are still neglected by many national and international climate change forums and policies (Copertino 2011). The Brazilian coast, as many other coasts, is highly vulnerable to present-day climate variability and may be profoundly impacted by the projected climate change (Muehe 2006, Neves & Muehe 2008). These impacts would pose serious threats to coastal biodiversity, ecological functions and services to society, including the coastal zone's carbon sequestration capacity. However, studies on Brazilian coastal vulnerability to GCC were few and isolated, owing in part to the fact that the country's coastal zone is very extensive.

In an attempt to fill this gap in current information, a Coastal Zone (CZ) project was established within the framework and aims of the National Institute of Sciences and Technology (INCT) for Climate Change and the Brazilian Network for Global Climate Change (Rede CLIMA). The full historic context of these large research programs and their first results are found in their activity report (INCT for Climate Change, 2010). A brief overview is given by Garcia & Nobre in the foreword of this volume. Formed by nearly 50 scientists, the multidisciplinary and interinstitucional CZ network aims to evaluate the current state of knowledge, identify deficiencies, establish protocols, integrate/coordinated projects and design scientific questions in several GCC-related research topics. The goals of the project are to investigate the impacts of climate change on the Brazilian coast and to determine the coast's vulnerability to these changes. The CZ project also seeks to propose mitigation and adaptation measures to compensate for and to buffer the impacts of climate change.

To achieve these goals, the CZ project organised the "First Brazilian Workshop on Climate Change and Coastal Zones", which was hosted by the Federal University of Rio Grande (FURG) (Figure 1). The workshop brought together experts from fourteen national institutions and took important steps that facilitated the attainment of the first project goals. In this three-day workshop, experts evaluated the status of the current knowledge of Brazilian coastal systems and processes and

presented their preliminary results. In addition, participants offered recommendations for future studies. The information gathered in the workshop resulted in fifteen scientific articles that comprise this Special Issue of the *Pan-American Journal of Aquatic Sciences*. In this editorial paper, we provide an overview and we also highlight the main findings of these articles, placing their importance and relevance in the perspective of Brazilian coastal zones facing climate change.

**Overview of the volume content**

The Brazilian coastline is almost 9,000 km long and includes a variety of coastal features such as sedimentary cliffs, large and deeply incised estuaries, crystalline headlands and low-lying coastal plains. By conducting a broad introductory review on the morphology and vulnerability of the Brazilian coastal zone, Muehe explores how each coastal region will respond in different ways to the expected climate changes and associated sea-level rise. The author concludes that erosion, although irregularly distributed, is affecting the entire shoreline. The risk of erosion can be magnified by sea-level rise and by the increase in the frequency and intensity of storms. The southern Brazilian coastline, for example, is exposed very often to extreme events, *i.e.*, storm surges and storm waves, mostly associated with extra-tropical cyclones. The frequency and intensity of these extreme events and their effects on erosion over the past 30 years is analysed by Machado *et al*., who report a total of 40 extreme events associated with maximum erosion and surge elevation in Rio Grande do Sul State. If the predicted sea-level rise occurs, the rise will certainly increase the importance of the already-existing storm surge hazards by intensifying inundation and the resulting erosion. In another contribution, Muehe *et al*. show that erosive trends are not evident for some coastal-plain areas in Rio de Janeiro State. However, the lack of sediment sources can make the system highly vulnerable to sea-level rise. The sandy dune system is highly vulnerable to changes in water balance. These changes can affect the sparse foredune vegetation cover and have drastic consequences for sediment transport and coastal morphology. The study has profound implications for predicting the effects of temperature increases and rainfall on the fragile morpho-sedimentary balance in these coastal plains.

The vulnerability of the Brazilian coastal zone to climate change and the hazards and risks involved are evaluate by Nicolodi & Petermann, who take into account the natural, social and technological characteristics of each coastal geographic region. Based on broad-scale and detailed information for each region, the authors indicate the main economic sectors likely to be affected and identify different levels of vulnerability. The areas identified as high and very high vulnerable should be at the top of the priority list for climate change policies and plans. One of the most vulnerable areas affected by sea-level rise is the Recife (Pernambuco State) metropolitan centre. This intensely populated area is highly exposed to coastal erosion and inundation and is the site of several land use conflicts. Based on optimistic and pessimistic IPCC emission scenarios, Costa *et al*. conduct a vulnerability and impact assessment for the region. They define coastal and estuarine flooding zones and discuss the natural, historical-cultural and economic resources at risk. Both studies provide guidance for preventive strategies to adapt to the effects of climate change.

The overall consensus seems to be that different Brazilian coastal regions will certainly be affected and will respond in different ways to climate changes. However, further predictions, particularly concerning sea-level rise, are very limited. Lemos & Ghisolfi show that most of the tide-gauge measurements performed along the coast are not accurate. This widespread inaccuracy thus places a serious limitation on attempts to clearly define the effects of global warming on the mean sea level along the Brazilian coast. These authors investigate the causes for this lack of accuracy and report that methodological, technological and institutional problems need to be addressed to provide better estimates of the sea level.

Brazil is home to the third-largest mangrove area in the world (Giri *et al*. 2011). Brazilian artisanal fishers are highly dependent on these mangrove systems, which occupy 80% of the coastline and have been threatened by several anthropogenic impacts. Faraco *et al*. propose an innovative methodology to assess the vulnerability of mangrove system to climate change, adapted to Brazilian reality. The proposal includes not only sea-level rise estimates but also resilience and adaptation capacity of the communities and the impacts of Brazilian conservation policies. The integrated socio-ecological diagnosis and approach may lead to a challenge in the development of management practices and more flexible policies, which are made with the stakeholder´s participation, including mitigation and adaptation strategies.

Also important for conservation, fishing and tourism, Brazilian coral reefs are exposed to several kinds of natural and anthropogenic impacts. Corals have been degraded worldwide by eutrophication,

pollution and overfishing (Hughes et al. 2007). They are also seriously threaten by climate changes impacts such as ocean acidification and warming that are leading to decreased growth rates and increasing bleaching and diseases (Anthony et al. 2008, De´ath et al. 2009, Wild 2011). The status of the coral reefs of Brazil is reviewed by Leão *et al*., who identify the reefs that are more stressed by anthropogenic impacts and more vulnerable to climate change effects. The review provides an important basis for establishing priorities for future research and conservation plans for these unique Brazilian marine systems, which are marked by a resistant relict coral fauna and a high level of endemism.

The study of modes of large-scale climate variability in relation to regional climate and oceanographic parameters can reveal trends that are fundamental to GCC studies. Focusing on the responses of large marine ecosystems (LMEs), Gherardi *et al.* explore spatial patterns of correlation between several climate indices (Pacific Decadal Oscillation, ENSO, North and South Atlantic and Antarctic Oscillation Index) and sea surface temperature anomalies (SSTA) for the Southwest Atlantic. Their findings reveal distinct correlation patterns for the Brazilian LMEs. The authors point out that the response of LMEs to climatic variability may not be controlled by the ecological criteria used to define the LMEs. The characteristics of the dependence on the SSTA of productivity and trophic relations in each of the Brazilian LMEs are such that mixed responses are likely to be produced at the ecosystem level. Therefore, despite the great importance of this framework for marine resource assessment and management, the use of LME responses for monitoring GCC impacts requires great caution.

Changes in global primary production have been showed by several studies over the past decades, in association with multi-decadal climate and ocean variability (Chavez *et al.* 2011). Climate driven changes in ocean temperature, nutrients and light lead to changes in phytoplankton biomass and structure, but the relative importance of the impacts and the biological responses are regionally varying (Marinov *et al*. 2010). The lack of long-term biological observations makes it difficult to detect robust changes with time at regional scales. Ciotti *et al.* used satellite data to conduct a first comparative evaluation of surface chlorophyll over the entire Brazilian continental shelf (BCS), characterising each region. The authors conclude that the detection of long-term trends is currently still not feasible for the BCS. Despite the paucity of *in situ* measurements and the optical complexity associated with Brazilian coastal waters, remote sensing of ocean color is undoubtedly the best available tool for a global description of chlorophyll and to predict the effects of GCC on marine primary production. The use of these techniques in Brazilian science should be enhanced.

Rainfall distribution and hydrological balance are likely to be affected by GCC (Meehl *et al.* 2007). Lake and lagoon levels are among the most apparent signals of change in water quantity. The water catchment surface area is much greater than the lake itself, and the water level can therefore visibly reflect the influence of climate on a relatively large area (Williamson *et al.* 2009). By analysing 90 years of water-level records for Mirim Lagoon (Brazil-Uruguay frontier), Hirata *et al*. find long-term changes strongly associated with ENSO and identified two regime shifts, apparently related to the cold and warm phases of the Pacific Decadal Oscillation during the previous century. The last warm phase, between 1977 and 1998, significantly affected the water balance of a wide region in Southern South America (Haylook et al. 2006, Agosta and Compagnucci 2008). Hirata and co-authors work provides key insights for predicting the possible effects of trends in regime shifts and of climate change on the water balance of the coastal lagoons and wetlands of southern Brazil.

Fisheries may be impacted by climate changes in several ways. They may be affected by the increasing temperature, changes in salinity and ocean currents, and also through the changes in nursery habitats and ecosystem primary production. Combining IPCC emission scenarios with regional climate models, climate and biological time series data, and accounting for local anthropogenic alterations, Shroeder & Castello evaluate the future impacts of global warming on the fisheries of Patos Lagoon. They predict that the main factor affecting fisheries in this region will be the acceleration of the outflow current at the mouth of the lagoon. This hydrological change will have important cones-quences for the population dynamics of valuable fish resources and may produce changes to the fishing calendar. Exploring a series of cause-effect relationship, the authors call attention for the fact that climate changes impacts on the local fisheries can be both negative and positive, depending on the factor and on the considered species.

Global warming is expect to affect the distribution of marine communities and many evidences of species shifting and changing abundance are raising from literature (Hoegh-Guldberg 2010). Previous biological knowledge and

a comparison of present and past data allow De Faveri *et al.* to find important changes in an intertidal macroalgal community in southern Brazil (Santa Catarina State). The results include the appearance of tropical and opportunist species not previously described in this region, and the disappearance of local common taxa that used to occur in the 70´s decade. Many marine population responses to temperature increases are expected to be pronounced or to be initially detected in transitional warm-temperate regions, such as Southern Brazilian region. On rock shores, however, climate change may not lead to a simple poleward shift in the distribution of intertidal organisms but may cause localized extinctions, due to the inability of species to move into suitable habitats (Hawkins et al. 2008).Therefore, monitoring marine populations, with a focus on stenothermic species, can provide useful indicators of climate change effects, particularly where historical temperature data are not available.

The contributions appearing in the present volume deal mainly with climate variability and its potential impacts during the previous decades or the past century. In contrast, Medeanic & Correa go further back through recent geological time. Based on radiocarbon and palynomorphic data from cores, these authors make a preliminary paleore-construction of climate, sea-level oscillation and environmental changes in the coastal plain of the southernmost state of Brazil during the Holocene (~10,000 B.P.). Their work highlights the potential of palynomorph proxies as a tool to predict future scenarios based on climatic change periodicity.

The crucial role of scientific communication and media coverage on the GCC issue is also considered in this volume. Hellebrandt & Hellebrandt review the coverage of GCC by the Brazilian media and identified critical points. Among these points is the predominance of issues set by an international scientific and political agenda. The Brazilian media reproduces information provided by international agencies and news sources connected with this agenda, which overlooks both local reality and scientific expertise. Failure to communicate key messages about climate change, particularly if the regional context is not considered, can have negative implications for public awareness and for establishing climate change policies.

**Final remarks**

If the physics of climate change still involves many uncertainties, the impacts of climate change on coastal and marine ecosystems are still very much controversial, particularly in the case of analysis at the regional level. It seems relatively less complicated to predict the effects of a changing parameter (*e.g.*, rising temperature, acidification and decreasing light) on isolated species from previous knowledge about their physiology, ecology and reproductive biology. However, many challenges arise when predicting the responses at the community and ecosystem level, in addition to the complexity added by synergistic effects (Walther et al. 2002, Williams *et al.* 2008, Russel *et al.* 2009, Hoegh-Guldberg & Bruno 2010). Therefore, the challenge posed to the worldwide scientific community working with GCC and its impacts is paramount and will demand the best of our talent and creativity.

The papers presented in this Special Issue constitute a first step towards the provision of guidance to managers and policymakers who must address the impacts of GCC in the Brazilian coastal zone, particularly in relation to the Climate Change National Plan. However, a series of scientific goals still need to be achieved to evaluate the effects of climate change on the Brazilian coastal zone. These goals include the analysis and integration of historical data, the application of standardised protocols, hypothesis testing, and continuous data acquisition programmes specifically designed to observe the coastal environments.

For most Brazilian coastal ecosystems and regions, temporal and large spatial data is scarce for both biotic and abiotic parameters. Where available, information is isolated, punctual in space, with short and incomplete time series (if any). Most studies also lack integrated or comparative protocol consistency. Scientific evaluations and future planning on the impacts of climate change along Brazilian coastal zone will achieve development if observational systems are implemented and improved to allow systematic monitoring programs of physical, chemical, biological and social parameters. Experimental approaches can help climate change science and management, but only after a better determination of questions and hypothesis, that are specific to each regional condition.

By researching GCC, science and scientists cannot be apart from society. Public awareness and education may affect, at middle and long term, society opinion, behaviour and political decisions, contributing for the advance of climate change policies and actions. The *Rio Grande Declaration*, an open letter released soon after the Workshop and now officially published in this volume, constitutes a preliminary attempt of CZ members and meeting participants to contribute to awareness and influence

public policies. The letter warns about climate change problems, particularly the ones affecting the coast, and claims for society and political action.

By indicating deficiencies and revealing scientific hurdles, and pointing out the consequences for ecosystems and society, the present volume is expected to offer new insights and stimulate future studies of impacts, mitigation measures and adaptation strategies for Brazilian coastal zones facing Global Climate Change. It is also envisaged that this initial step will foster new knowledge that will represent a significant Brazilian contribution to international scientific forums addressing this important issue.

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**Figure 1**. Participants of the I Brazilian Workshop on Climate Changes in Coastal Zones, hosted by the Federal University of Rio Grande, between September 14th and 16th 2009. The event was promoted by Coastal Zone Network from National Institute of Science and Technology (INCT) for Climate Change, and supported by CNPq.

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