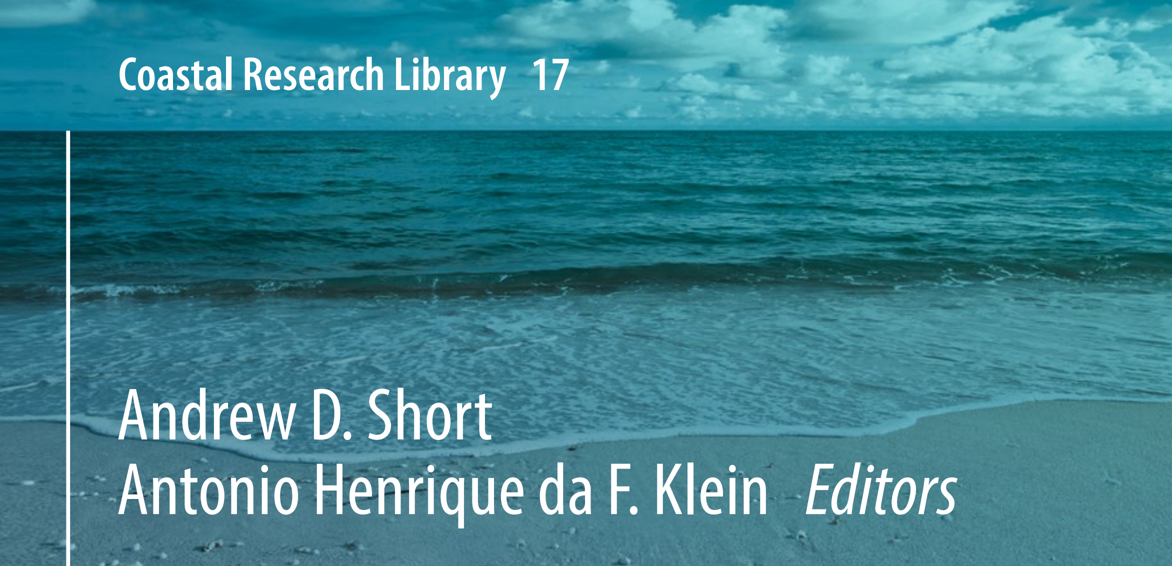

Coastal Research Library 17

Andrew D. Short
Antonio Henrique da F. Klein *Editors*

Brazilian Beach Systems

Springer

Coastal Research Library

Volume 17

Series Editor
Charles W. Finkl
Department of Geosciences
Florida Atlantic University
Boca Raton, FL 33431, USA

The aim of this book series is to disseminate information to the coastal research community. The Series covers all aspects of coastal research including but not limited to relevant aspects of geological sciences, biology (incl. ecology and coastal marine ecosystems), geomorphology (physical geography), climate, littoral oceanography, coastal hydraulics, environmental (resource) management, engineering, and remote sensing. Policy, coastal law, and relevant issues such as conflict resolution and risk management would also be covered by the Series. The scope of the Series is broad and with a unique cross-disciplinary nature. The Series would tend to focus on topics that are of current interest and which carry some import as opposed to traditional titles that are esoteric and non-controversial. Monographs as well as contributed volumes are welcomed.

More information about this series at http://www.springer.com/series/8795

Andrew D. Short • Antonio Henrique da F. Klein
Editors

Brazilian Beach Systems

Springer

Editors
Andrew D. Short
School of Geosciences
University of Sydney
Sydney, NSW, Australia

Antonio Henrique da F. Klein
Departamento de Geociências, Laboratório de Oceanografia Costeira
Universidade Federal de Santa Catarina
Florianópolis, SC, Brazil

ISSN 2211-0577 ISSN 2211-0585 (electronic)
Coastal Research Library
ISBN 978-3-319-30392-5 ISBN 978-3-319-30394-9 (eBook)
DOI 10.1007/978-3-319-30394-9

Library of Congress Control Number: 2016944928

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

To ***Professors Dieter Carl Ernst Heino Muehe and João José Bigarella (in Memoriam)***
for ongoing leadership in Brazilian beach research

Foreword

It's likely that no one on Earth has visited more beaches than Andrew Short. In Australia alone, he visited 11,670, publishing seven books. Andy studied at the Coastal Studies Institute at Louisiana State University (LSU) where studies of applied coastal morphodynamics in the beach environment began. Then in the 1970s to 1980s, he was part of the University of Sydney's Coastal Studies Unit, which demonstrated the co-evolution of morphology and hydrodynamics explaining more thoroughly and completely the behavior of the beach and surf zone. In this way, a series of basic and logical parameters were defined and adapted, to provide the key elements to a global classification system of sandy beaches. These parameters that define beach systems were well-received internationally due to their simplicity and efficiency in explaining the interaction of sand and waves in beach behavior. Surprisingly, Andy and his colleagues defined beach stages and their behavior through years of morphodynamic field observation by the naked eye, a decade before the application of video monitoring of surf zones complimented their findings. Equally notable, they applied their findings to improve beach safety, focusing on the risks and dangers of the beach environment.

In reality, Andy has frequented the coast of Brazil since 1975 when he was part of one of the first morphodynamic studies conducted in Brazil on beach systems of Sergipe and Pernambuco. I met Andy in a hotel bar in Chile during the Sandy Beach'94, where we made notes and diagrams on napkins over a few cups of pisco sour. It cost us a hangover, which was only cured after a dip in the cold waters of the Valdivia beaches. Sixteen years ago, I had the privilege of showing him the beaches of my home state from Cassino beach to Chuí, RS. On this trip, we climbed up two lighthouses, Albardão and Fronteira Aberta, to observe the beach systems: fortunately the latter of the two only collapsed two weeks after our visit.

Antonio Klein began his Brazilian beach excursions in the 1990s during his undergraduate studies at the Universidade Federal do Rio Grande (FURG). At this time, Klein and I were doing beach surveys of the southern coast with a level and rod; Klein, who was new to the marine environment, would only move seaward after sounding the sea floor with the rod. Even so, he decided to study Concheiros do Albardão, a beach unique to the southern littoral of Rio Grande do Sul for its deposits of seashell fragments and quartz sand. With this research, he completed his master's at the Universidade Federal do Rio Grande do Sul (UFRGS) in Marine Geology. He continued his work as professor at the Universidade do Vale do Itajaí (UNIVALI) in the state of Santa Catarina, where he researched the application of coastal morphodynamics in beach safety, eventually developing an award-winning project that reduced the number of swimming accidents on the Santa Catarina coast. Between 1999 and 2004 in Portugal during his PhD, he pioneered some of the first notable studies on the beaches of Santa Catarina, focusing on embayed beaches limited by rocky headlands, which constitute the majority of Santa Catarina's beaches. In 2010, he moved to Federal University of Santa Catarina (UFSC), and this book is a result of his first research project at this university.

It is not surprising that the collaboration of these two beach enthusiasts, Andy and Klein, would result in a book of this scope and importance. This book is an unprecedented approach to Brazilian beach systems from Amapá to Rio Grande do Sul. The book begins by locating Brazilian beaches in a global classification model according to the relative importance of their principal variables: tide range and wave energy, as well as presenting the evolution of Brazilian beach studies, including management, erosion, and beach safety. This initial focus is followed by the classification of the Brazilian coastal provinces by geological inheritance, geomorphology, hydrodynamic regime, and climate. They assembled researchers with different areas of expertise in coastal geology and geomorphology from the seventeen Brazilian coastal states to improve our present knowledge of Brazilian beach systems. The book concludes with a summary of all that is known about Brazilian beach systems and what still needs to be investigated to improve our knowledge of the system as a whole. It recommends directions for future research and is a valuable tool for those responsible for coastal management.

This book is a unique opportunity in that it presents the physical variability of Brazilian oceanic beaches in a logical and accessible form, particularly for those passionate about the study of beach systems and their connections to other areas of knowledge. Students and professionals in areas such as oceanography, geography, geology, coastal engineering, and coastal management will find this book a valuable resource in their development and understanding of the mechanisms that govern beaches, hopefully using this knowledge in real life application to benefit their communities. This work is essential in the library of all those that are fascinated by oceanic beaches.

Lauro Júlio Calliari
Institute of Oceanography
Federal University of Rio Grande (FURG)
Rio Grande, RS, Brazil
November 15, 2015

Preface

This book is a culmination of decades of fieldwork, research, and publications on the many beaches that line the magnificent coast of Brazil. This research commenced tentatively and sporadically in the 1960s and mushroomed in the 1990s, cumulating in 2000 with the First Brazilian Sandy Beaches Symposium, which contained 67 presentations by Brazilian coastal researchers.

Today coastal and beach research is underway in every one of the 17 coastal states, as evidenced by the contents of this book. The first editor was introduced to the Brazilian coast in 1975 and has returned multiple times to visit and work on the coast from Amapá in the north to Rio Grande do Sul in the south. The second editor introduced embayed beach morphodynamics and beach hazards and risk to Brazil and has supervised 18 graduate students, most with coastal-beach topics, many of whom have gone on to form the basis of the next generation of Brazilian coastal scientists and managers.

This book is about the beaches of Brazil. These beaches are both a vital and the major component of the Brazilian coast, and a source of endless fascination and recreation for the Brazilian people. All Brazilians know about their coast and beaches and most seem to want to vacation there in the summer months. This combination of people and coast has however resulted in some problems, ranging from a personal level with beach safety, to a national level with coastal development. In order to address these problems, one must begin with a good knowledge of the beaches and how they behave. This book addresses both these problems as well as documenting our present knowledge of the Brazilian coast and its beautiful, abundant, and wide-ranging beach systems.

This book contains 20 chapters written by 58 authors, who between them know all that is presently known about the Brazilian coast and in particular its beach systems. Seventeen of those chapters provide a state-by-state assessment of the beaches in each state, together with introductory, island beaches, and final a review and overview chapter.

If you are wondering why an Australian is editing a book on Brazilian beaches, it has to do with my 40-year association with the Brazilian coast and the assistance of a wonderful group of Brazilian coastal colleagues who have taken the time to show me, talk about, and discuss their beautiful coast and its beach systems. I also have the good fortune to see and visit much of the Brazilian coast, always with my Brazilian colleagues. I would particularly like to thank the following for taking their time to show me some of the following coasts:

Amapá – Valdenira Santos; Pará – Nils Asp and Luci Pereira; Ceará – Jader Onofre Morais; Rio Grande do Notre – Helenice Vital; Natal to Recife – Rodolfo Angulo; Fernando de Noronha – Lauro Calliari; Recife to Vitoria – Pedro Pereira and Lauro Calliari; Espírito Santo – Jacqueline Albino; Rio de Janerio – Dieter Muehe; São Paulo – Michel Mahiques; Paraná – Rodolfo Angulo; Santa Catarina – Antonio Klein; Rio Grande do Sul – Lauro Calliari, Sergio Dillenburg, and Elírio Toldo.

Sydney, NSW, Australia — Andrew D. Short
Florianópolis, SC, Brazil — Antonio Henrique da F. Klein

Acknowledgments

We first and foremost thank our 58 colleagues in Brazil and Spain for their contributions to this book, as well as the 19 reviewers listed below who assisted the editors in reviewing all the chapters. Without you all, this book would not exist.

This book could also not have been achieved without the support of CNPq – *Science Without Borders Program* which provided funding for a 3 years (2013–2015) Visiting Professor Grant at UFSC – Graduate Geographer Program and Graduate Oceanographer Program, project no. 400302/2012-8 (Coastal Hazards and Headland Sediment Bypassing Assessment in Different Coastal Environments), part of which resulted in the compilation and editing of this book. This work also had the financial support of the following programs: Programa de Formação em Recursos Humanos em Geologia da Petrobras (PFRH-PB 240); Fundo Clima – Ministério do Meio Ambiente, project MMA-Riscos; and SMC Project (MMA) and Bolsa de Produtividade em Pesquisa – Nível 2 [Proc. No. 303550/2012-0]).

The following are thanked for reviewing the chapters:

Javier Alcantara-Carrió, Edward J Anthony, Jarbas Bonnetti Filho, Lauro J Calliari, J Andrew G Cooper, Paolo Ciavola, João M Alveirinho Dias, Oscar Ferreira, Duncan FitzGerald, Mauricio Gonzales, Federico Isla, Guilherme Lessa, Dieter Muehe, Pedro Pereira, Klaus Schwarzer, Tim Scott, Karl Stattegger, Allan Williams, and Colin Woodroffe.

At UFSC, we thank José Mauricio de Camargo and Charline Dalinghaus for assisting with figures and tables.

At Springer, we especially thank Petra van Steenbergen who set us off on the path to this book, and Marielle Klijn who guided us through the preparation and submission and review of the manuscript and Mrs. Rathika Ramkumar who oversaw the final editing, proofing and production of the book. We also thank Charles W. Finkl, the Coastal Research Library Series Editor, for this ongoing support and enthusiasm for the project.

Contents

Editors and List of Contributors

Editors

Andrew D. Short School of Geosciences, University of Sydney, Sydney, NSW, Australia

Antonio Henrique da F. Klein Departamento de Geociências, Laboratório de Oceanografia Costeira, Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil

Contributors

Jacqueline Albino Department of Oceanography and Ecology, Universidade Federal do Espírito Santo, Vitória, ES, Brazil

Javier Alcántara-Carrió Oceanographic Institute of the University of São Paulo (IOUSP), São Paulo, SP, Brazil

Rodolfo José Angulo Departamento de Geologia, Laboratório de Estudos Costeiros – Lecost, Universidade Federal do Paraná, Setor de Ciências da Terra, Curitiba, Paraná, Brazil

Tereza Cristina Medeiros de Araújo Geological Oceanography Laboratory, Department of Oceanography, Center of Geoscience and Technology, Federal University of Pernambuco, Recife, PE, Brazil

Elisabeth Mary de Carvalho Baptista Núcleo de Estudos sobre a Zona Costeira do Estado do Piauí – NEZCPI, Universidade Estadual do Piauí – UESPI, Curso de Licenciatura Plena em Geografia, Teresina, PI, Brazil

Abílio Carlos da Silva Pinto Bittencourt Institute of Geosciences, UFBA, BA, Brazil

Jarbas Bonetti Departamento de Geociências, Laboratório de Oceanografia Costeira, Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil

Carlos Alberto Borzone Laboratório de Ecologia de Praias, Centro de Estudos do Mar, Universidade Federal do Paraná, Setor de Ciências da Terra, Pontal do Paraná, Paraná, Brazil

Lauro Júlio Calliari Institute of Oceanography, Federal University of Rio Grande, Rio Grande, RS, Brazil

Marcelo dos Santos Chaves Departamento de Geografia, Centro de Ciências Sociais e Aplicadas, Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil

Nery Contti Neto Department of Oceanography and Ecology, Universidade Federal do Espírito Santo, Vitória, ES, Brazil

José Maria Landim Dominguez Institute of Geosciences, UFBA, BA, Brazil

Catherine Fitzpatrick Institute of Oceanography, Federal University of Rio Grande, Rio Grande, RS, Brazil

Maria Luzineide Gomes Núcleo de Estudos de Geografia Física – NEGEO, Universidade Estadual do Piauí – UESPI, Curso de Licenciatura Plena em Geografia, Teresina, PI, Brazil

Moab Praxedes Gomes Departamento de Geologia/Programa de pós-Graduação em Geodinâmica e Geofísica, Centro de Ciências Exatas e da Terra, Universidade Federal do Rio Grande do Norte-UFRN Campus Universitário, Natal, RN, Brazil

Mauricio González Rodríguez Instituto de Hidráulica Ambiental de la Universidad de Cantabria "IHCantabria", Universidad de Cantabria, Santander, Spain

Omar Quetzalcóatl Gutiérrez Instituto de Hidráulica Ambiental de la Universidad de Cantabria "IHCantabria", Universidad de Cantabria, Santander, Spain

Antonio Espejo Hermosa Instituto de Hidráulica Ambiental de la Universidad de Cantabria "IHCantabria", Universidad de Cantabria, Santander, Spain

Zuleide Maria Carvalho Lima Departamento de Geografia/Programa de pós-Graduação em Geografia/UFRN/, Centro de Ciências Sociais e Aplicadas, Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil

Flavia Moraes Lins-de-Barros Departamento de Geografia/Programa de Pós Graduação em Geografia, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

Verónica Cánovas Losada Instituto de Hidráulica Ambiental de la Universidad de Cantabria "IHCantabria", Universidad de Cantabria, Santander, Spain

Arthur A. Machado Institute of Oceanography, Federal University of Rio Grande, Rio Grande, RS, Brazil

Michel Michaelovitch de Mahiques Oceanographic Institute of the University of São Paulo (IOUSP), São Paulo, SP, Brazil

Luis Parente Maia LABOMAR-Instituto de Ciências do Mar, Universidade Federal do Ceará, Fortaleza, CE, Brazil

Valdir do Amaral Vaz Manso Marine Geophysical and Geology Laboratory, Department of Geology, Center of Geoscience and Technology, Federal University of Pernambuco, Recife, PE, Brazil

Cristina Celia Martins Fundação de Estudos e Pesquisas Aquáticas, Fundação de Estudos e Pesquisas Aquáticas, Sao Paulo, SP, Brazil

Amilcar Carvalho Mendes Museu Paraense Emílio Goeldi-MPEG, Campus de Pesquisa, Coordenação de ciências da Terra e Ecologia, Belém, PA, Brazil

Jáder Onofre de Morais Laboratório de Geologia e Geomorfologia Costeira e Oceânica-LGCO, Universidade Estadual do Ceará, Fortaleza, CE, Brazil

Dieter Muehe Graduate Program in Geography, Universidade Federal do Espirito Santo, Vitória, Brazil

Lucas do Nascimento Prefeitura Municipal de Camaçari, Camaçari, Bahia, Brazil

Wellington Nascimento Trindade Instituto de Estudos Costeiros, Universidade Federal do Pará, Bragança, Pará, Brazil

Silvana Moreira Neves Department of Geographical Sciences, UFPE Campus Universitário, Recife, Pernambuco, Brazil

João Luiz Nicolodi Instituto de Oceanografia (IO), Universidade Federal de Rio Grande (FURG), Rio Grande, RS, Brazil

Mauricio Almeida Noernberg Centro de Estudos do Mar, Laboratório de Oceanografia Costeira e Geoprocessamento, Universidade Federal do Paraná, Setor de Ciências da Terra, Paraná, Brazil

Tiago Castro Alves Oliveira Environmental Engineering Department, Universidade Federal do Espírito Santo, Vitória, ES, Brazil

Jorge Eduardo de Abreu Paula Núcleo de Estudos de Geografia Física – NEGEO, Universidade Estadual do Piauí – UESPI, Curso de Licenciatura Plena em Geografia, Teresina, PI, Brazil

Luci Cajueiro Carneiro Pereira Instituto de Estudos Costeiros, Universidade Federal do Pará, Bragança, Pará, Brazil

Pedro de Souza Pereira Geological Oceanography Laboratory, Center of Geoscience and Technology, Oceanography Department, Federal University of Pernambuco, Recife, PE, Brazil

Felipe M. Pimenta Departamento de Geociências, Centro de Filosofia e Ciências Humanas, Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil

Francisco Pinheiro Lima-Filho Departamento de Geologia/Programa de pós-Graduação em Geodinâmica e Geofísica, Centro de Ciências Exatas e da Terra, Universidade Federal do Rio Grande do Norte-UFRN Campus Universitário, Natal, RN, Brazil

Lidriana de Souza Pinheiro Instituto de Ciências do Mar-LABOMAR- Federal University of Ceará, Fortaleza, CE, Brazil

Yuri G. Pinheiro Institute of Oceanography, Federal University of Rio Grande, Rio Grande, RS, Brazil

Clécio José Lopes de Quadros Departamento de Geologia, Laboratório de Estudos Costeiros – Lecost, Universidade Federal do Paraná, Setor de Ciências da Terra, Curitiba, Paraná, Brazil

Leonardo Cruz da Rosa Departamento de Engenharia de Pesca e Aquicultura, Laboratório de Ecologia Bentônica, Universidade Federal de Sergipe, Centro de Ciências Agrárias Aplicadas, São Cristóvão, Sergipe, Brazil

Adeylan Nascimento Santos School of Engineering and Information Technology, UNIFACS, Salvador, Bahia, Brazil

Valdenira Ferreira dos Santos Instituto de Pesquisas Científicas e Tecnológicas do Estado do Amapá-IEPA, Núcleo de Pesquisas Aquáticas – NuPAq, Macapá, AP, Brazil

Eduardo Siegle Oceanographic Institute of the University of São Paulo (IOUSP), São Paulo, SP, Brazil

Filipe Galiforni Silva Oceanographic Institute of the University of São Paulo (IOUSP), São Paulo, SP, Brazil

Iracely Rodrigues da Silva Instituto de Estudos Costeiros, Universidade Federal do Pará, Bragança, Pará, Brazil

Iracema Miranda da Silveira Museu Câmara Cascudo Universidade Federal do Rio Grande do Norte- UFRN, Natal, RN, Brazil

Fernando C. Sobral Institute of Oceanography, Federal University of Rio Grande, Rio Grande, RS, Brazil

Paulo Henrique Gomes de Oliveira Sousa Oceanographic Institute of the University of São Paulo (IOUSP), São Paulo, SP, Brazil

Flavo Elano Soares de Souza Centro de Tecnologia, Colégio Agrícola de Jundiaí, Universidade Federal do Rio Grande do Norte, UFRN, Macaiba, RN, Brazil

Maria Cristina de Souza Departamento de Geologia, Laboratório de Estudos Costeiros – Lecost, Universidade Federal do Paraná, Setor de Ciências da Terra, Curitiba, Paraná, Brazil

Werner Farkatt Tabosa Departamento de Geologia/Programa de pós-Graduação em Geodinâmica e Geofísica, Centro de Ciências Exatas e da Terra, Universidade Federal do Rio Grande do Norte-UFRN Campus Universitário, Natal, RN, Brazil

Elírio Ernestino Toldo Jr. Centro de Estudos de Geologia Costeira e Oceânica, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

Ana Vila-Concejo School of Geosciences, University of Sydney, Sydney, NSW, Australia

Helenice Vital Departamento de Geologia/Programa de pós-Graduação em Geodinâmica e Geofísica, Centro de Ciências Exatas e da Terra, Universidade Federal do Rio Grande do Norte-UFRN Campus Universitário, Natal, RN, Brazil

Chapter 1
Brazilian Beach Systems: Introduction

Antonio Henrique da F. Klein and Andrew D. Short

Abstract Brazil possesses one of the great national coastlines of the world, extending for approximately 9000 km between latitudes 4°N and 34°S. The Amazon, the world largest river dominates the northern 1500 km. South of the Amazon, sandy beaches increasingly dominate the shore with more than 4000 beaches occupying much of the coast. This chapter provides an overview of the range of beach systems that occupy the Brazilian coast. This is followed by a review of previous research on the Brazilian coast together with management issues facing the coast. It then provides an updated classification of the entire coast, dividing it into seven coastal regions based on coastal processes, geology and geomorphology, that include from the northern Amazon Gulf mud coast; Northern tide-dominated; Northern tide-modified; Northeast wave-dominated; Eastern wave-dominated, Southeast wave-dominated; and Southern wave-dominated.

1.1 Introduction

Brazil possesses one of the great national coastlines of the world, extending for approximately 9000 km between latitudes 4°N and 34°S. The coast is a classic trailing edge coast typified by numerous long meandering rivers, generally low gradient regressive coastal plains, an abundance of sediment and extensive beach-barrier systems. The Amazon, the world largest river in terms of discharge and sediment supply, dominates the northern 1500 km, maintaining a predominately mangrove-fringed mud-dominated shore, with scattered sandy beaches. South of the Amazon, however, sandy beaches increasingly dominate the shore with more than 4000 beaches occupying much of the coast and comprising 2 % of all coastal ecosystems

A.H. da F. Klein (✉)
Departamento de Geociências, Laboratório de Oceanografia Costeira,
Universidade Federal de Santa Catarina,
Florianópolis, SC 88040-900, Brazil
e-mail: antonio.klein@ufsc.br

A.D. Short
School of Geosciences, University of Sydney, Sydney, NSW 2006, Australia
e-mail: andrew.short@sydney.edu.au

A.D. Short, A.H. da F. Klein (eds.), *Brazilian Beach Systems*, Coastal Research Library 17, DOI 10.1007/978-3-319-30394-9_1

(82,778 ha) (Muehe 2003). The remaining coast is occupied by rocky shore, inlets and in sheltered locations mangroves, as well as salt-marsh in the south.

This book is about the beach systems that dominate most of the Brazilian coast. They include one of the world's longest beach-barrier systems, the 610 km long strip of sand and dunes that extend from Torres, south along the entire coast of Rio Grande do Sul, to the border at Chuí. This system includes the 242 km long Hermenegildo-Cassino beach and 193 km long Tavares-Tramandaí beach, the longest beaches in South America and some of the longest in the world. There are many other long beaches associated with extensive river deltas and coastal plains; together with embayed and small pocket beaches bordered by headlands and inlets; as well as numerous beaches located in lee of beachrock reefs and in some areas fringing coral reefs.

The entire coast is bordered by the Atlantic Ocean and much is exposed to easterly trade winds and to east through southerly seas and swell, which combined provide considerable energy to transport sediment and construct a wide range of beach, barrier, inlet and deltaic forms. Wave energy ranges from low to moderate along the tide-dominated Amapá and Pará coasts, where considerable wave attenuation takes place across the shallow inshore, to moderate along the Maranhão, Ceará and northern Rio Grande do Norte coast, to moderate to high energy along the long southeast-facing east coast. The waves drive predominately northerly longshore sand transport, which has been calculated to reach 1 Mm^3 $year^{-1}$ in some locations, together with some local and seasonal reversals in sediment transport. Tides also vary considerably with the north coast dominated by macro to mega-tides reaching 11 m in the mouth of the Amazon, decreasing to macro and meso north and east of the mouth. The east coast has meso-tides in the north and along parts of the central coast grading to micro-tides towards the south, with the lowest tide range (~0.5 m) along the coast of Rio Grande do Sul. Tidal currents are significant along the north coast with the flood tides trending to the west reinforcing the easterly wind and wave driven currents and the strong North Brazil current. The easterly Trade winds dominate much of the northeast and north coast, while southeast winds dominate the east coast down to Santa Catarina Island, south of which there is a shift to northerly wind dominance. From Rio de Janeiro to the south storm surges up to 1.0 m high contribute to coastal processes.

The considerable range in wave and tide energy maintains the full range of beach types and states along the open coast. In the north the beaches are generally tide-dominated to tide-modified, while along the east coast they range from tide-modified in the northeast to wave-dominated along the central and southern sectors, with tide-dominated beaches predominating in sheltered bays and estuaries. The beaches span the tropical to subtropical latitudes and in northeast are modified by coral and beachrock reefs, which induce the formation of lower energy crenulate beaches in their lee. Also in the north and east the Barreiras Formation outcrops along sections of coast forming eroding cliffs, and in the south particularly between Carbo Frio and Cabo de Sta. Marta numerous bedrock headlands produce many embayed and pocket beach systems.

Brazil's numerous sandy beaches are synonymous with Brazil. Not just because they occupy the majority of the coast, but also because of the way Brazilian life and lifestyle have evolved and adapted to this seemingly endless stretch of tropical and subtropical sand beaches. Almost 20 % of Brazil's population lives in coastal counties (Muehe 2003), and most major cities, except São Paulo and Brasília, are coastal, it total more than 40 million Brazilian's live near the coast and its beaches. While the coast has long been the location of all ports and smaller fishing communities, since the 1970s there has been a surge towards the coast. This has resulted in a rapid expansion of existing towns and cities as well as the development of extensive housing and second-house subdivisions and in favorable locations the growth of tourist centers with highrise hotels and resorts. All of this is bringing more people to the coast both permanently and on vacation. The resulting pressure on the beaches and their backing barriers and dunes is often intense as dunes are leveled for development, tall structures crowd the shore and overshadow the afternoon beach, and effluent pollutes the beaches.

At the same time these same beaches will be the most susceptible parts of the coast to the impacts of climate change. They are literally caught between rapidly increasing human pressure and more subtle but equally intense changing sea level and climate. As a consequence they are presently and will continue to experience considerable human and natural impacts.

It is the *aim* of this book for the first time to both document and assess the nature, dynamics and state of Brazil's beach systems on a state-by-state basis. While the book will primarily focus on the physical characteristics of the beaches and their morphodynamics, it will also touch on the impact these systems have on beach users, through the hazards they present, as well as briefly review the nature and level of development along the coast.

The book is arranged into 20 *chapters*. This chapter introduces the topic and reviews the history of beach studies in Brazil, the way the coast is classified, the range of beach types along the coast, the type of beach hazards and the general impact of population pressure and development along the coast. The following 19 chapters (Chaps. 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20) begin with an overview of Brazilian coastal processes particularly the wave, tide and wind regimes (Chap. 2), followed by a state-by-state coverage of the beach systems, starting in the north at Amapá and extending south to Rio Grande do Sul including a chapter on Brazil's ocean island beaches (Chaps. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19). It finishes (Chap. 20) with an overview of both the nature and status of Brazil's beaches, as well as addressing areas where more research is required.

1.2 Brazilian Beaches

This section briefly reviews the range of beach types and states that occur globally and along the Brazilian coast, and that will be presented in more detail in each of the chapters. It then looks at some the major issues facing Brazilian beaches including beach management, erosion and safety; this is followed by a classification of the Brazilian coast (Sect. 1.3) into seven coastal regions, each of which is then described (Sect. 1.4).

1.2.1 Beach Types and States

Brazilian beach systems can be classified into three types based on relative tide range (RTR) (Masselink and Short 1993), where

$$RTR = TR / H_b \tag{1.1}$$

where TR = mean spring tide range (m) and H_b = breaker wave height (m). This parameter quantifies the relative contribution of waves and tides. When waves are relatively high and tides low and RTR < 3 beaches are *wave-dominated*. Between 3 and ~10 they are *tide-modified*; and when waves are very low and tide relatively high and RTR is between ~10 and ~50 they become *tide-dominated* (Fig. 1.1; Short 2006).

The Brazilian coast has tides ranging from 0.5 to 11 m and low though high waves. It therefore contains RTR's ranging from <1 to >50 and the full range of wave-dominated, tide-modified and tide-dominated beach types. The three beach types can be further classified into 13 beach states using the dimensionless fall velocity (Ω) (Gourlay 1968), where

$$\Omega = H_b / W_s T \tag{1.2}$$

where W_s = sediment fall velocity (m s^{-1}) and T = wave period (s).

Ω quantifies the relative contribution of wave height and period and sediment grain size (expressed as sediment fall velocity) to beach morphodynamics. Using Ω *wave-dominated beaches* can be classified into six beach states (Fig. 1.1). When waves are relatively low, periods long and sand coarse Ω < 1, the beaches are narrow and barless and called *reflective*. When waves are moderate to high (Ω = 2–5) the beaches become rip-dominated *intermediate* with usually one or two bars cut by rip channels and currents. When wave are high and sand is fine Ω > 6 the beaches become wide and *dissipative* with often multiple (2–4) shore parallel sand bars. Figure 1.1 illustrates the six wave-dominated beach states.

Tide-modified beaches go though a similar transition with the addition of a usually wide low tide bar and consist of three beach states (Fig. 1.1). The lower energy reflective state (Ω < 1) consists of a reflective high tide beach plus a wide (~100 m+) low tide terrace. The intermediate state contains a reflective high tide beach and low tide bar cut by rip channels (Ω = 2–5) on its outer low tide sector; while the higher energy dissipative state features a very wide (>200 m) low gradient featureless concave ultradissipative beach when Ω > 6 (Fig. 1.1).

The *tide-dominated beaches* consist of four states each fronted by wide intertidal sand and/or mud flats (100's–1000's m wide). They range from a low energy high tide beach fronted by ridged sand flats under higher waves, through to very low energy sand flats, tidal sand flats and finally tidal mud flats (Fig. 1.1). For a full description of the beach types and states see Short (1999, 2006).

In addition two other beach states can occur along the coast, these are high tide reflective sandy beaches fronted by intertidal rocks flats or beachrock reefs, and high tide beaches fringed by intertidal coral reef flats (Fig. 1.1). Both are common along parts of the Brazilian coast, particularly where beachrock and coral reefs fringe the shore.

In total the three beach types and rock/reef flat beaches account for 15 different beach states ranging from the high energy wave-dominated multi-bar dissipative with surf zones 300–500 m wide, to barless reflective beaches; to with increasing tide range the tide-modified beaches with surf; to the very low energy tide-dominated beaches fronted by tidal flats. Table 1.1 list the beach types and states, their abbreviations and general relationship to RTR, Ω and H_b. Note that the actual relationship

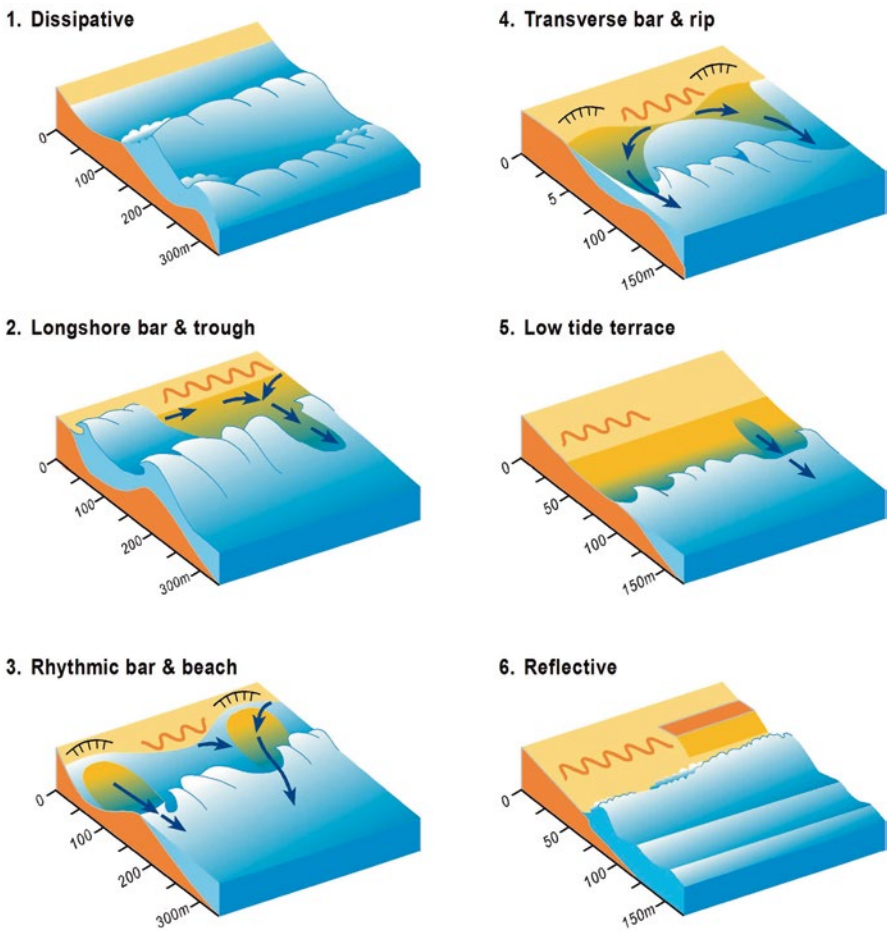

Fig. 1.1 Schematic sketch of wave-dominated (1–6), tide-modified (7–9) and tide-dominated beaches states (10–13); and beaches fronted by rock or reefs flats (14 and 15) (Source: Short and Woodroffe 2009)

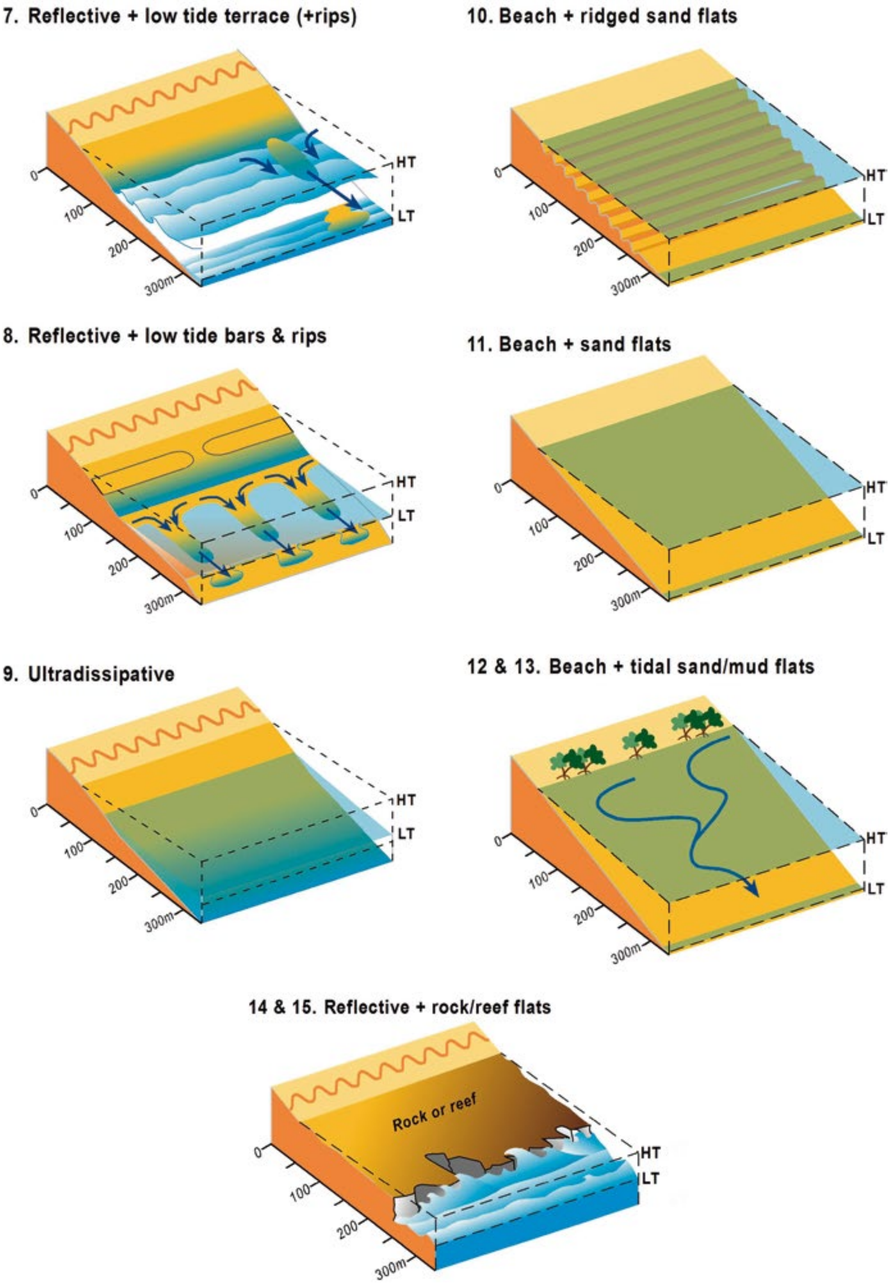

Fig. 1.1 (continued)

Table 1.1 List of the three beach types and 15 beach states and some of their environmental characteristics

No.	Abbreviation	Beach state	RTR	Ω	~H_b (m)
Wave dominated			<3	1–6	
1	D	Dissipative	<1	>6	>2
		Intermediate	<3		
2	LBT	Longshore bar & trough	<3	~5	<2
3	RBB	Rhythmic bar & beach	<3	~4	>1.5
4	TBR	Transverse bar & rip	<3	~3	~1.5
5	LTT	Low tide terrace	<3	~2	~1
6	R	Reflective	<3	~1	<1
Tide-modified			3 ~ 10	1–6	
7	R + LTT	Reflective + low tide terrace		~1	<1
8	R + LTR	Reflective + low tide bar & rips		~3	~1
9	UD	Ultradissipative		>5	~1
Tide-dominated			~10 ~ 50	<1	<<1
10	B[#] + RSR <0.5	Beach + ridged sand flats		<1	<0.5
11	B + SF	Beach + sand flats		<1	<0.3
12	B + TSF	Beach + tidal sand flats		<1	<0.2
13	B + TMF	Beach + tidal mud flats		<1	<0.2
*Rocks/reef**					
14	R + RF	Reflective + rock flats	–	–	–
15	R + CF	Reflective + coral reef flats	–	–	–

The RTR, Ω and H_b are all approximate and will vary between wave environments, while 14 and 15 are independent of waves and tides (Short 1999). Also see Fig. 1.1.
[#]Beach indicates a very low energy strip of high tide sand
[*]Rock and reef fronted beaches form independently of RTR, Ω and H_b

will vary with wave environments and need to be determined locally. The beaches fronted by rocks flats or coral reefs are independent of waves and tides.

The relationship between the wave-dominated, tide-modified and tide-dominated beach states and H_b, W_s and RTR is also presented in Fig. 1.2. Figure 1.2a plots the impact of increasing Ω and RTR on beach type and state while Fig. 1.2b plots the relation between beach state and H_b, sand size and RTR. It shows how wave-dominated beaches have the highest waves and lowest RTR with fine to medium sand, with a coarsening towards the reflective end. Tide-modified beaches have moderate waves, increasing RTR and medium more poorly sorted sand; while tide-dominated beaches have low waves, high RTR and the coarsest material, which is very poorly sorted. The figures are based on Australian data and made need modification in other coastal environments.

The forgoing applies to beaches in general and is largely based on Australian studies. However Brazil, like Australia, has tides ranging from micro to mega, and waves from low to high, together with beach sand ranging from fine to coarse. One would therefore expect all the above beach types to be found along the Brazilian coast, which is in fact the case, as will be presented in the following chapters.

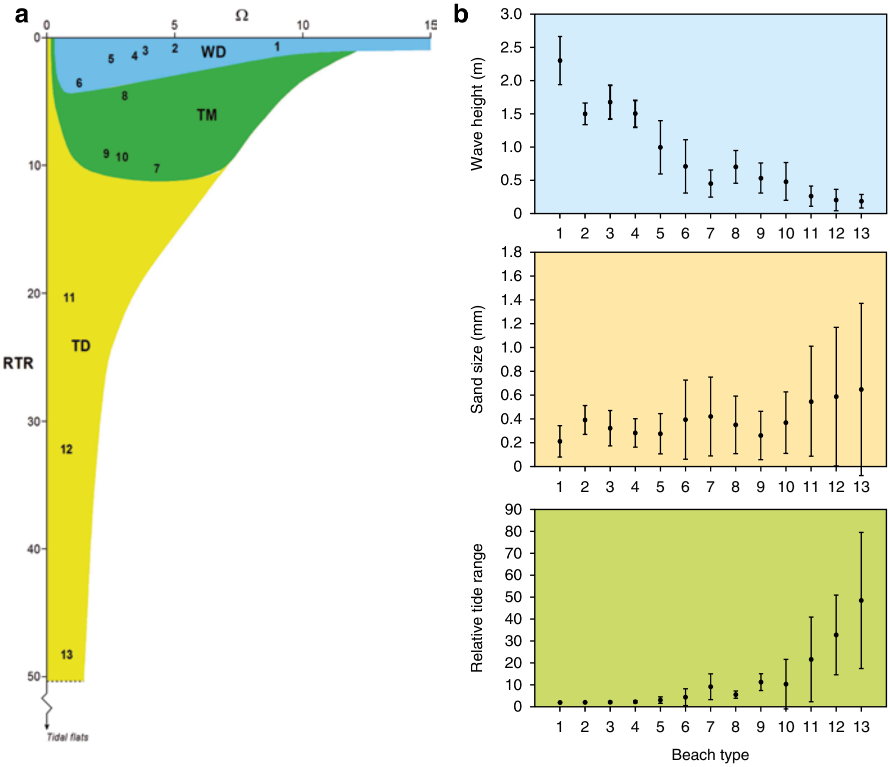

Fig. 1.2 Relationship between Ω and RTR in controlling beach type and state (*WD* wave-dominated, *TM* tide-modified, *TD* tide-dominated) (Source: Short and Jackson 2013); and (**b**) the relationship (mean and standard deviation) between the wave-dominated (1–6), tide-modified (7–9) and tide-dominated (10–13) beach states and H_b, sand size and RTR (Source: Short and Woodroffe 2009). All data are based on Australian beaches and may need modification for other coastal environments. See Table 1.1 for number legend

1.2.2 *Brazilian Beach Studies*

The scientific study of Brazilian beaches commenced indirectly with the publication by Darwin (1881) on the '*bar of sandstone*' (beachrock) at Recife. A century later these reefs were further studied and dated by Mabesoone (1964). During the 1960s studies of beach sediment were made in southern Brazil by Bigarella et al. (1966) and Martins and Eichler (1969). While the extensive reefs and beach sediments continue to warrant considerable study, the first publication examining the actual beaches were beach profile studies undertaken by Ottman et al. (1959) in Recife; and Kowsmann (1970) at Copacabana Beach; while Muehe (1979) presented more regional beach studies of the coast of Rio de Janeiro. The first beach morphodynamic investigations were undertaken by Suhayda et al. (1977). This team from