Coral Reefs of the World 18

Vassil N. Zlatarski · John K. Reed
Shirley A. Pomponi · Sandra Brooke
Stephanie Farrington *Editors*

Coral Reefs of Cuba

Springer

Coral Reefs of the World

Volume 18

Coral Reefs of the World is a series presenting the status of knowledge of the world's coral reefs authored by leading scientists. The volumes are organized according to political or regional oceanographic boundaries. Emphasis is put on providing authoritative overviews of biology and geology, explaining the origins and peculiarities of coral reefs in each region. The information is so organized that it is up to date and can be used as a general reference and entry-point for further study. The series will cover all recent and many of the fossil coral reefs of the world.

Prospective authors and/or editors should consult the Series Editors B.M. Riegl and R.E. Dodge for more details. Any comments or suggestions for future volumes are welcomed:

Dr. Bernhard M. Riegl/Dr. Richard E. Dodge
Nova Southeastern University
Dania Beach, FL 33004
USA
e-mail: rieglb@nova.edu and dodge@nova.edu

Vassil N. Zlatarski • John K. Reed •
Shirley A. Pomponi • Sandra Brooke •
Stephanie Farrington
Editors

Coral Reefs of Cuba

Springer

Editors
Vassil N. Zlatarski
Independent Scientist
Bristol, RI, USA

John K. Reed
Harbor Branch Oceanographic Institute
Florida Atlantic University
Fort Pierce, FL, USA

Shirley A. Pomponi
Harbor Branch Oceanographic Institute
Florida Atlantic University
Fort Pierce, FL, USA

Sandra Brooke
Coastal and Marine Lab
Florida State University
St. Teresa, FL, USA

Stephanie Farrington
Techglobal Inc
Rockville, MD, USA

ISSN 2213-719X ISSN 2213-7203 (electronic)
Coral Reefs of the World
ISBN 978-3-031-36718-2 ISBN 978-3-031-36719-9 (eBook)
https://doi.org/10.1007/978-3-031-36719-9

Cover Image: Satellite image of the reticulate coral reef system Grand Banco de Buena Esperanza, SE Cuba. © Spalding MD, Rivilious C, Green EP (2001) World Atlas of Coral Reefs. Univ California Press.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Cuba is the largest island in the Caribbean and a hotspot of biological diversity. Its vast land area with wonderfully diverse and rich habitats is matched by its wealth in marine resources—among them one of the biggest coral reef systems in the Caribbean. For coral reef scientists, Cuba has long been a promised, yet for many forbidden, land and final frontier of marine research and exploration. The vagaries of politics have long caused a relative isolation of this biodiverse, culturally and scientifically rich island with a vibrant academic culture and strong research. While information about its reefs and the work of its scientific community was of course available, the sheer biogeographic and ecological importance as well as the vast academic capability of this island's scientists merits to be highlighted in a special contribution to this book series. This is exactly what this present volume, "Coral Reefs of Cuba," which is number 18 in the series "Coral Reefs of the World," aims to do.

This book was produced with the goal of providing an overview of the status of knowledge of Cuban coral reefs and to provide a baseline from which further investigations can depart. Importantly, it opens much of the knowledge that has been developed inside Cuba and its institutions in an easily accessible way to a wider international, English-speaking, audience. It is a scholarly review as opposed to a status report and there is no claim that the materials presented are complete and will satisfy everybody's interest. Nonetheless, it should become a key work of reference of where to start reading when interested in Cuba's reefs and the citations contained within will also serve as a guide to an important body of literature that is not always so easy to come by.

Experts from within and without Cuba have collaborated to present in this volume the widest possible overview of present knowledge of these most interesting reef systems. Cuba has been a cradle of modern reef research, which is highlighted by V. Zlatarski's first chapter giving a rich overview of what can be learned from Cuban reefs. Zlatarski himself is one of the pioneers of modern coral reef research who has been investigating these reefs since the 1970s. The research history of Cuba's reefs is treated in a separate chapter by S. González-Ferrer (Chap. 2), himself a key player.

Part III is a special section of the volume dedicated to the physical description of the reef edifices as a whole. The physico-geographic properties of the modern reefs (Chap. 3 by Estrada Estrada et al.), the relevance of the uplifted marine terraces for modern reefs (Chap. 4 by Iturralde-Vincent and Hine), and the use of remote sensing to describe extent and geomorphology of the reefs (Chap. 5, Andréfouët and Bionaz) are discussed.

Part IV treats the distribution and nature of biota, and these chapters should be of key interest to anybody working anywhere in the Caribbean, given Cuba's central role to connectivity. Among the benthos, the macrophyte flora (Chap. 6, Suárez and Martínez-Daranas), the sponge fauna (Chap. 7, Busutil and García-Hernández), the stony corals (Chap. 8, González-Ferrer, Cairns and Zlatarski) and octocorals, so important on Caribbean reef systems (Chap. 9, Rey-Villiers et al.), are treated in detail. Chapters on reef mollusks (Chap. 10, Espinosa and González-Ferrer), herbivory and herbivores (Chap. 11, Duran et al.), the Lionfish invasion (Chap. 12, Chevalier Monteagudo et al.), and ecological and fisheries aspects of sharks and rays (Chap. 13, Pina-Amargós et al.) provide a more process-oriented view for the reader.

Chapter 14 by Reed et al. describes the rich mesophotic (deep) reefs surrounding Cuba.

Part V leads us through the ecology of these reefs as relevant for conservation and management. We are informed on the status of coral reefs in Cuba (Chap. 15, Pina-Amargós et al.), the population genetics of corals (Chap. 16, Ulmo-Díaz et al.), and stressor effects in NW Cuba (Chap. 17, González-Díaz et al.). More regional aspects are described in chapters on the coral reefs in Guanahacabibes National Park (Chap. 18, Cobián-Rojas et al.), the Cienaga de Zapata Biosphere Reserve (Chap. 19, González-Méndez et al.), and in Cuba's marine protected areas in general (Chap. 20, Perera-Valerrama et al.). These chapters reveal the strong approach taken in Cuba to the conservation of these critically important ecosystems.

The final Part VI of the volume deals with economic valuation of reefs (Chap. 21 by Figueiredo-Martín et al. and Chap. 22 by Ferro-Azcona et al.) and the fish that live within (Chap. 23 by Figueiredo-Martín and Pina-Amargós).

Even after just glancing cursorily over the chapters presented in this volume, there will no doubt in anybody's mind about the importance of Cuba's coral reefs and the hard work and competence of its scientists. As editors of the book series, we thank authors and volume editors for the hard work that has gone into the production of this beautiful contribution. It should have a place of honor in any library or any interested person's bookshelf and we are certain that it will be amply cited.

Dania Beach, FL, USA — Bernhard Riegl
March 2023 — Richard Dodge

Preface

Cuban coral reefs are uniquely valuable and important, as demonstrated by Hawthorne L. Beyer and 20 colleagues (Risk-sensitive planning for conserving coral reefs under rapid climate change. Conservation Letters. 2018;11:e12587. https://doi.org/10.1111/conl.12587). They identified a global portfolio of 50 bioclimatic units (BCUs) for conservation investment that maximizes the chances these coral reefs are secure in the future. Five of the 50 BCUs in the entire world are in Cuba (10%), as are five of the total of six in the Caribbean (83%)!

This volume represents the first English language overview of Cuban coral ecosystems, which are among the healthiest in the Caribbean. It is our hope that this information will be of value to others who work on these fragile and endangered ecosystems.

This project was initiated in 2020 at the suggestion of Dr. Bernhard Riegl, Editor of the Series “Coral Reefs of the World.” It was an exciting and timely project, but it began under the difficult conditions of the COVID-19 pandemic. Since most of the authors spoke Spanish as their native language, the first challenge was to find qualified Editors who were also fluent in Spanish and English. From the original Editorial Board, Vassil Zlatarski and Sergio González-Ferrer developed the book structure and engaged the chapter authors. More than 100 colleagues enthusiastically joined the project and overcame the challenges of quarantine and disrupted communications to produce the first chapter drafts in Spanish and received editorial suggestions from Vassil and Sergio. Unfortunately, Sergio had to withdraw as Editor in January 2021, but continued to play a critical role in communicating with the Cuban authors and assisting with the editorial process as an “unofficial” Editor until the end of the project.

The next challenge was the translation of the Spanish manuscripts to English with limited financial resources. Some authors recruited translators, but additional assistance was generously provided by the Harte Research Institute (Texas Agricultural and Mechanical University-Corpus Christi) and the Environmental Defense Fund.

During the review period in October 2021, another member of the original editorial board (Benjamin J. Greenstein) had to withdraw, leaving the sole remaining Corresponding Editor to recall the words of Dr. Yossi Loya: “During the process of editing the mesophotic book, some authors got married, some divorced, and others had personal reasons for delaying their contribution. There were fires in California, Hurricanes demolishing labs, you name it.”

The dictum that there is always somebody who has the interest and is willing to devote their efforts to a worthwhile cause led to the present Editorial Board with four new members: John K. Reed, Shirley A. Pomponi, Sandra Brooke, and Stephanie Farrington. During 2022, John, Shirley, and Sandra contacted the reviewers to complete their reviews, edited the chapters for content and language, and finalized the reviews of each chapter’s multiple revisions. Special thanks to Stephanie for organizing the large number of documents and correspondence.

The Editorial Board is now happy to present the volume “Coral Reefs of Cuba” with deep gratitude for the tireless contributions of the enthusiastic authors, patient translators, generous facilitators, eminent experts, volunteer reviewers, and both former Co-Editors, all during extraordinary circumstances.

Bristol, RI, USA	Vassil N. Zlatarski
Fort Pierce, FL, USA	John K. Reed
Fort Pierce, FL, USA	Shirley A. Pomponi
St. Teresa, FL, USA	Sandra Brooke
Rockville, MD, USA	Stephanie Farrington

Contents

Part I Introduction

1 Insights from Cuban Coral Reefs . . . 3
Vassil N. Zlatarski

Part II History

2 Research History of Corals and Coral Reefs in Cuba . . . 19
Sergio González-Ferrer

Part III Description

3 Physical-Geographic Characteristics of Cuban Reefs . . . 51
Reinaldo Estrada Estrada, Gustavo Martín Morales, Joán Hernández-Albernas, Rodney Borrego Acevedo, Jorge Olivera Acosta, Yudelsy Carrillo Betancourt, Idalmis Almeida Martínez, and Lourdes Coya de la Fuente

4 Outline of the Geology, Geomorphology, and Evolution of the Late Quaternary Shelf and Uplifted Marine Terraces of Cuba: Tectonic and Sea-Level Control of Present-Day Coral Reef Distribution . . . 75
Manuel A. Iturralde-Vinent and Albert C. Hine

5 A Remote Sensing Appraisal of the Extent and Geomorphological Diversity of the Coral Reefs of Cuba . . . 93
Serge Andréfouët and Océane Bionaz

Part IV Biota

6 Macrophytes Associated with Cuban Coral Reefs . . . 111
Ana M. Suárez and Beatriz Martínez-Daranas

7 Sponges: Conspicuous Inhabitants of the Cuban Coral Reefs and Their Potential as Bioindicators of Contamination . . . 127
Linnet Busutil and María R. García-Hernández

8 Species List of Cuban Stony Corals: Class Anthozoa, Order Scleractinia; Class Hydrozoa, Suborders Capitata and Filifera . . . 147
Sergio González-Ferrer, Stephen D. Cairns, and Vassil N. Zlatarski

9 Octocoral Forests: Distribution, Abundance, and Species Richness in Cuban Coral Reefs . . . 163
Néstor Rey-Villiers, Leslie Hernández-Fernández, Hansel Caballero, Mayilen Triana López, Alejandro Pérez Angulo, and Yunier Olivera Espinosa

10 Current State of Knowledge of Reef Mollusks in Cuba 185
José Espinosa and Sergio González-Ferrer

11 Herbivory on Cuban Coral Reefs 199
Alain Duran, Patricia González-Díaz, Rodolfo Arias, Dorka Cobián-Rojas, Pedro Chevalier, Tamara Figueredo, Alain García-Rodríguez, Ariagna Lara, Yunier Olivera, Susana Perera-Valderrama, and Fabián Pina

12 Chronology of the Lionfish Invasion in Cuba and Evaluation of Impacts on Native Reef Fishes 215
Pedro Pablo Chevalier Monteagudo, Dorka Cobián Rojas, Raúl Igor Corrada Wong, Alexis Fernández Osoria, Hansel Caballero Aragón, Delmis Cabrera Guerra, Zenaida María Navarro Martínez, and Leandro Rodríguez Viera

13 Sharks and Rays in Cuban Coral Reefs: Ecology, Fisheries, and Conservation 229
Fabián Pina-Amargós, Yunier Olivera-Espinosa, Alexei Ruiz-Abierno, Rachel Graham, Robert Hueter, Juan Fernando Márquez-Farías, Aracelys Hernández-Betancourt, Raidel Borroto-Vejerano, Tamara Figueredo-Martín, Alejandra Briones, Yureidy Cabrera-Páez, Ariandy González-González, Consuelo Aguilar-Betancourt, and Gaspar González-Sansón

14 Mesophotic Coral Ecosystems of Cuba 253
John K. Reed, Patricia González-Díaz, Joshua D. Voss, Linnet Busutil, Cristina Diaz, Shirley A. Pomponi, Stephanie Farrington, Dorka Cobián-Rojas, Andrew David, Beatriz Martínez-Daranas, M. Dennis Hanisak, Juliett González Mendez, Alexis B. Sturm, Patricia M. González Sánchez, María Rosa García Hernández, Jorge Viamontes Fernández, Mingshun Jiang, Jack H. Laverick, and Vassil N. Zlatarski

Part V Ecology, Conservation and Management

15 Status of Cuban Coral Reefs 283
Fabián Pina-Amargós, Patricia González-Díaz, Gaspar González-Sansón, Consuelo Aguilar-Betancourt, Yandy Rodríguez-Cueto, Yunier Olivera-Espinosa, Tamara Figueredo-Martín, Néstor Rey-Villiers, Rodolfo Arias Barreto, Dorka Cobián-Rojas, Rodolfo Claro, Susana Perera-Valderrama, Zenaida María Navarro-Martínez, Enrique Reynaldo-de la Cruz, Alain Durán, Yenizeys Cabrales-Caballero, Leonardo Espinosa-Pantoja, Zaimiuri Hernández-González, Hansel Caballero-Aragón, Pedro Pablo Chevalier-Monteagudo, Juliett González-Méndez, Leslie Hernández-Fernández, Susel Castellanos-Iglesias, Ariagna Lara, Alain García-Rodríguez, Linnet Busutil, Carlos Luis Reyes Suz, Joán Irán Hernández-Albernas, Aloyma Semidey Ravelo, and Pedro Alcolado Prieto

16 Population Genetics of Cuba's Scleractinian Corals 309
Gabriela Ulmo-Díaz, Jessy Castellanos Gell, Didier Casane, Alexis Sturm, Joshua Voss, and Erik García-Machado

17 Multiple Cumulative Effects on Coral Reefs of the Northwestern Cuban Region 317
Patricia González-Díaz, Gaspar González-Sansón, Consuelo Aguilar-Betancourt, Néstor Rey-Villiers, Alain Duran, Orlando Perera Pérez, and Sergio Álvarez Fernández

18 Guanahacabibes National Park: Research, Monitoring, and Management for the Conservation of Coral Reefs 339
Dorka Cobián-Rojas, Susana Perera-Valderrama, Pedro Pablo Chevalier-Monteagudo, Juan J. Schmitter-Soto, Raúl Igor Corrada Wong, Elena de la Guardia Llansó, Juliett González Mendez, Alain García-Rodríguez, Joan Hernández-Albernas, Lázaro Márquez-Llauger, Zaimiuris Hernández-González, Leonardo Espinosa Pantoja, Patricia González-Díaz, and Hansel Caballero-Aragón

19 Ciénaga de Zapata Biosphere Reserve: Integrating Science with the Management of Coral Reefs 359
Juliett González-Méndez, Susana Perera-Valderrama, Hansel Caballero-Aragón, Dorka Cobián-Rojas, Pedro Chevalier Monteagudo, Tania Piñeiro Cordero, Reynaldo Santana Aguilar, Leyaní Caballero-Thiert, Raúl I. Corrada Wong, Silvia Patricia González-Díaz, Dinorah Millán Caballero, and Jorge Luis Jiménez Hernández

20 Coral Reefs in Cuban Marine-Protected Areas 375
Susana Perera-Valderrama, Juliett González-Méndez, Aylem Hernández-Ávila, Reinaldo Estrada-Estrada, Dorka Cobián-Rojas, Adonis Ramón-Puebla, Elena de la Guardia-Llansó, Hakna Ferro-Azcona, Joán Hernández-Albernas, Zaimiuri Hernández-González, Leonardo Espinosa-Pantoja, Ariagna Lara, Fabián Pina-Amargós, Patricia González-Díaz, Pedro Pablo Chevalier-Monteagudo, Néstor Rey-Villiers, Jorge Antonio Tamayo-Fonseca, and Hansel Caballero-Aragón

Part VI Economic Valuation

21 Economic Valuation of the Coral Reefs of Jardines de la Reina and Punta Francés National Parks, Cuba 395
Tamara Figueredo-Martín, Laura López-Castañeda, and Fabián Pina-Amargós

22 The Economic Value of Coral Reefs in the Context of Marine-Protected Areas: Experiences of the South Cuban Archipelago Project 415
Hakna Ferro-Azcona, Gloria de las Mercedes Gómez-País, Susana Perera-Valderrama, Dorka Cobián-Rojas, Alberto González-Tejeda, Berta Lizano-Machado, Adaris Calderín González, Orlando Acosta-Rodríguez, Raisa Escalona-Domenech, and Adonis Ramón-Puebla

23 Fish Can Be more Valuable Alive than Dead 429
Tamara Figueredo-Martín and Fabián Pina-Amargós

Part I

Introduction

Insights from Cuban Coral Reefs

1

Vassil N. Zlatarski

Abstract

In the 1970s, the Cuban coral reefs were the object of extensive exploration. The results were published in Spanish, Russian, French, and German but unfortunately remain relatively unknown. This chapter provides, for the first time, English translations of excerpts from the study of Cuban reefs conducted in 1970–1973. The obtained knowledge had been planned to be published in a monograph and colored atlas of photos of the underwater scleractinians, but only the monograph was published (in Russian, French, and Spanish). Recent specialists' opinions and the author's reflections offer present-day insights from Cuban coral reefs regarding different aspects of the pioneer investigation: sampling and material, methodology, area study, terminology, variability, hybridization and morphogenesis, invasion, state of Scleractinia knowledge, reef zonation, reticulated reefs on muddy bottom, and reef health and care.

Keywords

Coral reef types · Reef zonation · Ecology · MCEs · Scleractinia · Variability

1.1 Introduction

Cuban reefs represent the largest coral reef system in the Caribbean. It is therefore of great importance for a complete understanding of coral and reef dynamics in the Caribbean basin but compared to other more frequently visited locations like Jamaica or Mexico, information is still relatively sparse. However, much information has been collected over the years, even though it may not have been available in English. In the 1970s, Cuban reefs were the object of systematic international studies resulting in considerable ecosystem knowledge. The results were published in Spanish, Russian, French, and German but unfortunately remain relatively unknown (Zlatarski 1980, 1982, 2018b; see Chap. 2, Gonzalez-Ferrer). This chapter is an attempt to share some insights from a longtime researcher's interest in coral reefs and to consider how the results of the study conducted in Cuban waters in 1970–1973 resonate after all these many years. Since the original publication of the monograph "The scleractinians of Cuba" (Zlatarski 1980), some species and genus names have been synonymized, and new taxa were described. In these cases, the International Code of Zoological Nomenclature term *auct.* is used. This is a Latin term meaning "of authors," often given to indicate that a name is used in the sense of a number of subsequent authors and not in its (different) sense as established by the original author. The next two sections on reef types and ecological zonation (Sect. 1.2) and scleractinian ecology (Sect. 1.3) present, for the first time, English translations of excerpts from the monograph on Cuban scleractinians.

V. N. Zlatarski (✉)
Bristol, RI, USA

1.2 Coral Reef Types and Ecological Zonation of the Scleractinians

1.2.1 General Notes

Reefs abound in the Cuban archipelago. Of the three classic types of reefs (fringing, barrier, and atoll), only the first two were found, and a special type was found on the muddy bottom, observed only in the Gulf of Guacanayabo (Fig. 1.1).

The studied profiles are distributed according to reef type (Fig. 1.2): on the muddy bottom, six profiles; fringing reefs, 15; barrier reefs, 20; and three transitioning between the last two.

The following reasons were decisive for reef construction in Guacanayabo: the hydrodynamic pattern, the substrate, and the lack of competitors that inhabit the bottom (greater detail is available in Sect. 1.2.4).

V. N. Zlatarski et al. (eds.), *Coral Reefs of Cuba*, Coral Reefs of the World 18, https://doi.org/10.1007/978-3-031-36719-9_1

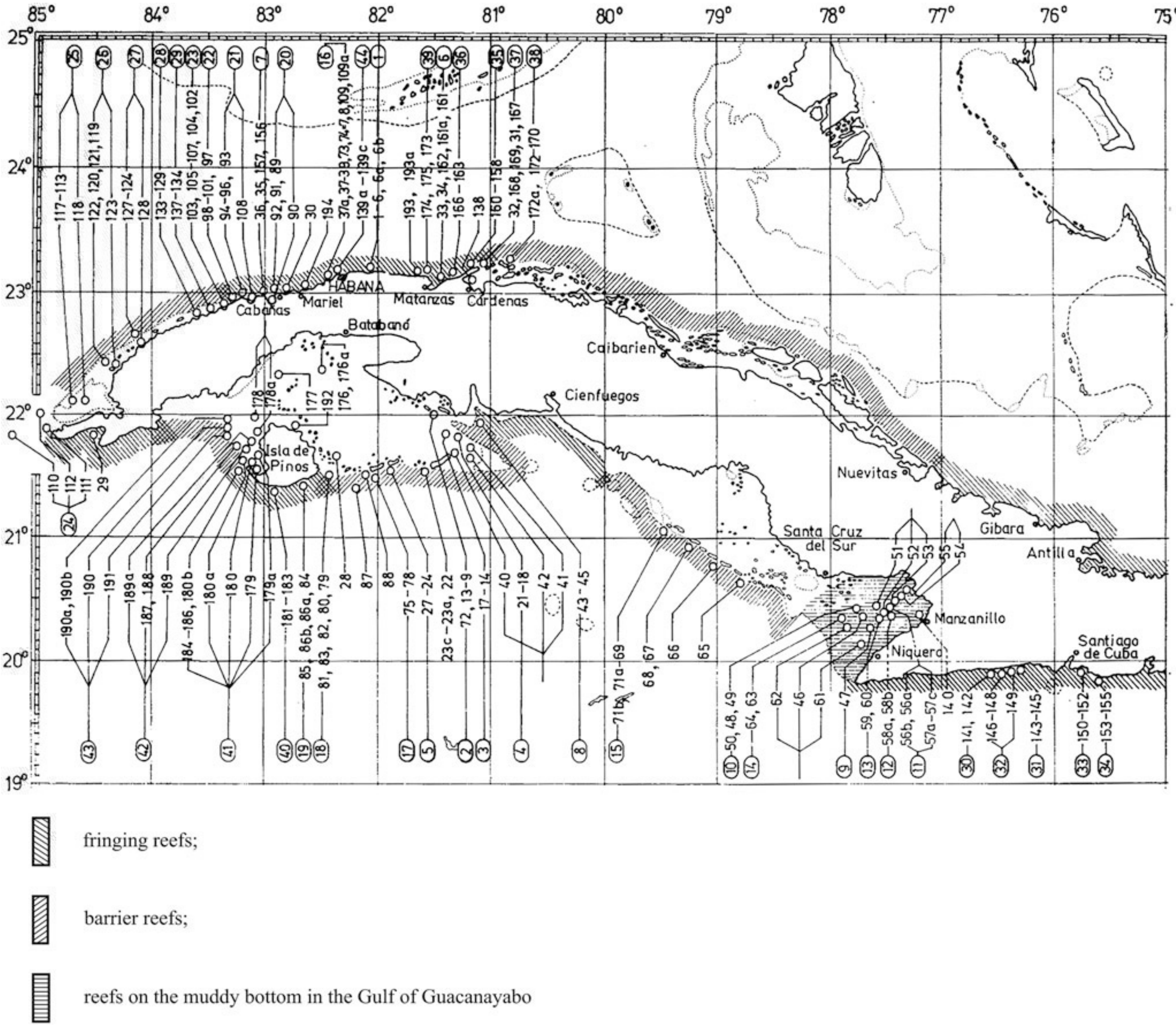


Fig. 1.1 Types of reefs in the Cuban archipelago

The data on salinity, temperature, and direction of the currents in Cuban waters (Núñez Jiménez 1970) signal that these physical–geographic conditions did not influence the formation of fringing and barrier reefs. A decisive factor behind the formation of these two types was the shelf width or, more exactly, the location of the limits between the shelf and the continental slope. There, the scleractinians have optimal living conditions, permanently clear and moving waters, and waters are rich in food particles. Further, the water–temperature variation in that area conditions the rapid accretion of sediment. Once the barrier has emerged by itself, it helps to further highlight the differences among nearby areas. Thus, when the shelf is wide, barrier reefs form, and when it is narrow or does not exist, fringing reefs arise. The width of the platform changes gradually as long as the boundaries between the two types of reefs are conditioned.

By scuba diving, it was established that reef formation also continues far from the breaker indicated by the reef barrier and away from the coasts abundantly covered with coral, occupying a larger space than that indicated for the shelf and the continental slope. Often, the continental slope at depths of 55–65 m and deeper was covered by scleractinians. Further, by penetrating deeper toward caverns along the bottom and caves, coral life was discovered in places that dredges could not reach.

The presence of reef formations, including small reef bodies with dimensions from a few meters to 10 or 20 m and with irregular contours, were observed in the sand channels in the reef barrier, in some lagoons, or in front of the fringing reefs. They are called cabezos (from "head" in Spanish; known as "coral head" or "coral knoll," in English; "massif corallien," in French) and were made up of huge

Fig. 1.2 Reef types of the Cuban archipelago (profile numbers refer to Fig. 1.1)

Number and name of profile	Types of reefs: Fringing reef	Barrier reef	Transitory between fringing and barrier reefs	On muddy bottom
1. Guanabo		x		
2. Cayo Diego Pérez		x		
3. Cayo Sigua		x		
4. Cayo Médano Vizcaíno		x		
5. Cayo Rosario		x		
6. Kilómetro 14	x			
7. Ortigosa		x		
8. Cayo Piedra (Costa Sur)		x		
9. Guacanayabo				x
10. Guacanayabo				x
11. Guacanayabo				x
12. Guacanayabo				x
13. Guacanayabo				x
14. Cayo Médano				x
15. Cayo Bretón		x		
16. Instituto de Oceonología			x	
17. Cayo Cantiles		x		
18. Cayo Matías		x		
19. Playa Larga		x		
20. Bahía de Cabañas	x			
21. Punta Gobernadora		x		
22. Morrillo		x		
23. Cayo Médano de Casiguas		x		
24. Cabo San Antonio	x			
25. Sancho Pardo		x		
26. Cayo Buena Vista		x		
27. Bajas		x		
28. Cayo Arenas		x		
29. Cayo Levisa		x		
30. Bayamita	x			
31. Punta Amarilla			x	
32. Cayo Damas	x			
33. Playa Siboney	x			
34. Playa Verraco			x	
35. Varadero	x			
36. Río Camarioca	x			
37. Cayo Piedra (Costa Norte)	x			
38. Cayo Cruz del Padre	x			
39. Punta Seboruco	x			
40. Carapachibey	x			
41. Punta Francés		x		
42. Cayo de los Indios	x			
43. Cayo del Perro	x			
44. Patricio Lumumba	x			

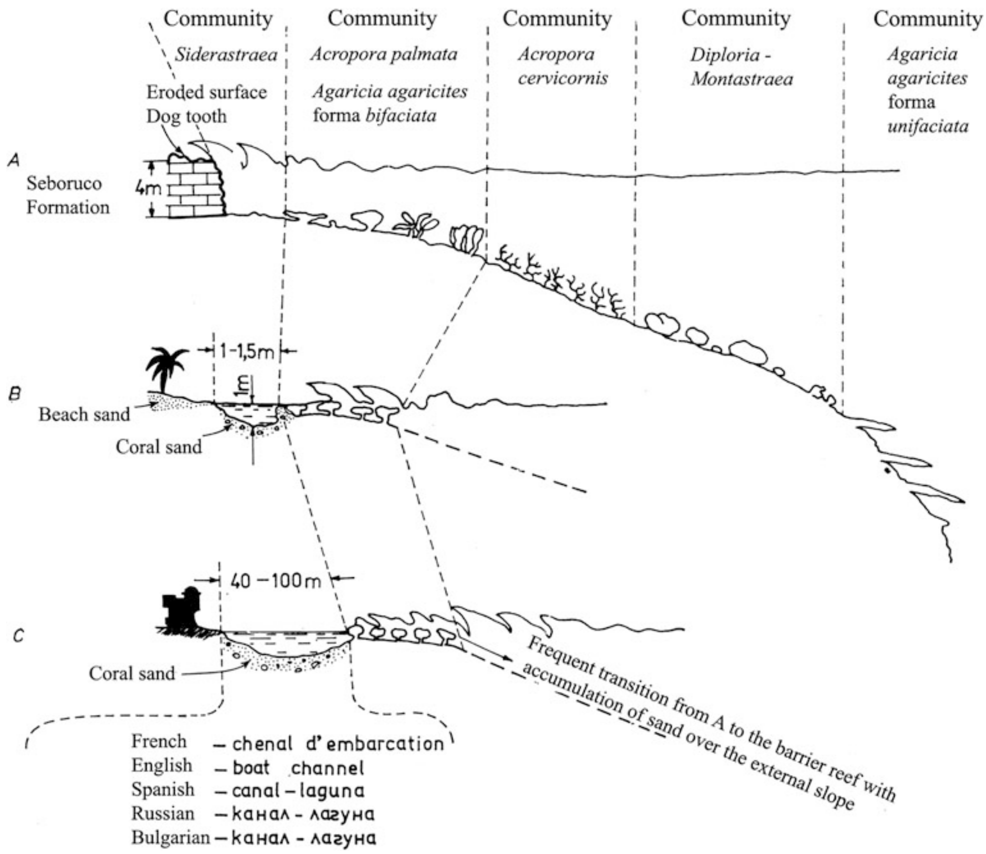


Fig. 1.3 Types of fringing reefs in Cuba and their zonation as seen in the 1970s; (**a**) fringing reef on steep rocky coast; (**b**) fringing reef on a slightly sloping sandy beach; (**c**) transition between fringing and barrier reefs

groups of coral colonies, which concentrate a world of organisms from the less inhabited nearby environment. The specific content was very diverse. Almost all the scleractinian species found in Cuban waters were found here.

Modern Cuban reefs are not considered thick (not exceeding 30 m). This is due to frequent changes in the sea level during the geological past. Many times, reefs emerged above sea level, and as a result of denudation, the colonies that formed them accumulated in terraces. These are the Pleistocene and Holocene coastal terraces that border much of the island. Reef formation was established during the Miocene, near the cities of Santiago de Cuba and Matanzas and in the former Province of Las Villas (this latter location also shows signs of reef formation during the Paleogene, with coral banks dating from the Upper Cretaceous).

1.2.2 Fringing Reefs

Fringing reefs emerged in the coastal areas between the large archipelagos (Fig. 1.1). In these locations, shelf width is negligible or simply virtually absent. In the latter case, the continental slope descends from the coast.

We confirmed that, in all their extension, the various fringing reefs are not inhabited by the same species of Scleractinia due to the heterogeneity of the ecological environment.

In one case, the shore rock abruptly drops vertically to a depth of 4 m or more (Fig. 1.3a; Profile 33, Playa Siboney; Profile 39, Punta Seboruco). Sea waves crash upon these rocks, hindering the growth of the corals and leaving rocks uninhabited. Only few flat colonies of *Siderastraea radians* were able to affix themselves and exist, strongly anchored to the bottom. Sometimes *Agaricia agaricites* forma *massiva* and *Diploria auct.* appeared. The community of Scleractinia in those poorly populated areas was dominated by *Siderastraea*. Moving away from the coast, colonies of *Acropora palmata* appeared. First, they were flat, short, and well affixed to the bottom; they increased in height with increasing depth and distance from the coastal waves. The branches appeared not only on a single plane, but instead, their colonies successively undertook isometric development. Here, the hydrodynamic movement was less intense. We can often find fragile colonies of *Agaricia agaricites* forma *bifaciata*. The community *Acropora palmata–Agaricia agaricites* forma *bifaciata* was followed by dense and graceful "shrubs" of *Acropora cervicornis*. This is why the community was also named after this species. Among them, perpendicular to the coastline, there were grooves or channels with depths of 1–3 m along which the compensatory

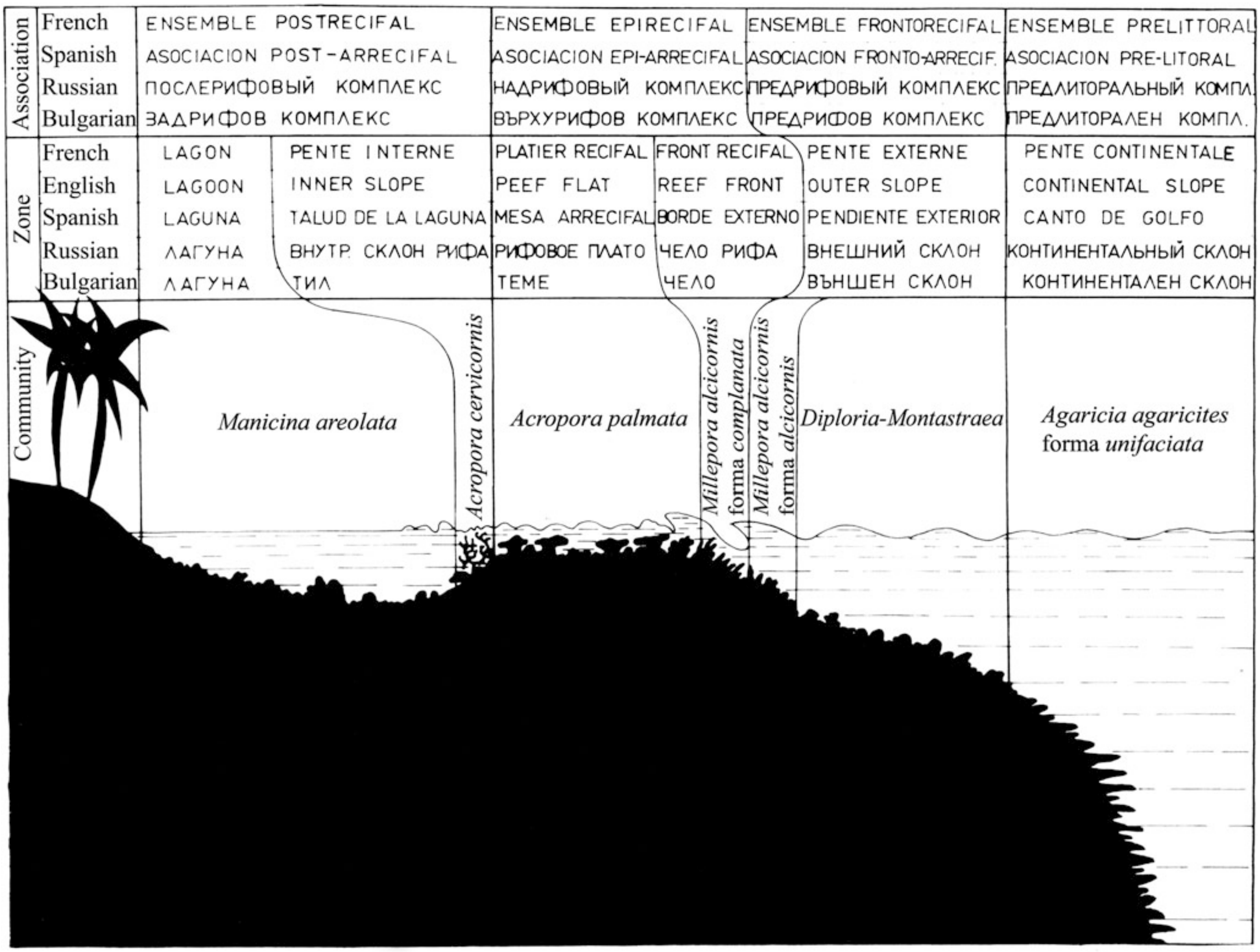


Fig. 1.4 Barrier reef zonation in Cuba as seen in the 1970s

movement of the bottom waters took place. Due to this movement, the bottom had bare rock or detrital sand. On the slopes, massive or spherical colonies arose, most often *Montastraea auct.* and *Diploria auct.* The community is named after *Diploria–Montastraea*. At greater depths, the conditions for coral life of fringing reefs and barrier reefs are similar; thus, the communities were similar, for which reason they will be discussed later.

When the coast was not made up of steep rock, but rather a slightly sloping sandy beach so that the impact of abrasion was much less, corals inhabited the bottom in the immediate vicinity of the coast (e.g., Fig. 1.3b and Profile 6, 14 km). Sometimes, a narrow (1–3 m) channel with sand at the bottom abutted the shore. In this case, the *Siderastraea* community did not take hold, and in general, the scleractinians were not found there. Behind the channel, moving away from the beach, *Acropora palmata* colonies again took on a predominant role, growing in dense, almost massive, low formations with short branches. Among them, in this profile, there were "oases" of *A. cervicornis*. Sometimes, the surface of the reef was covered by the massive growth of the soft coral *Zoanthus*. As the shelf widened, a lagoon channel was formed, and the zonation became increasingly similar to that of the barrier reef (Fig. 1.3c and Profile 16, Institute of Oceanology).

An extreme case was that of a wide band of coral sand that descended smoothly without coral inhabitants and a particular development of the fringing reef in front of Varadero (Profile 35). There, the sand bottom influenced the absence of the first communities. It only appeared on the outer slope of the reef and on the continental slope, where scleractinian life was more abundant.

In the transition type, the bottom of the outer slope of the reef and the continental slope also had the same number of scleractinian communities (see Figs. 1.3a and 1.4) as those of the fringing and barrier reefs, due to similar conditions. As the coast grew increasingly remote, communities of *Diploria–Montastraea* and *Agaricia agaricites* forma *unificata* continued.

1.2.3 Barrier Reefs

Barrier reefs emerge on a relatively wide shelf, i.e., when the continental slope is quite far from the coast. They grow near the edge of the shelf. This is why the reefs are facing the archipelagos of Los Colorados, Sabana-Camagüey, Jardines de la Reina, and Los Canarreos (Fig. 1.1). In the cuneiform area of the shelf, the previously mentioned type of transition was observed between the fringing and barrier reefs (Fig. 1.3c).

In barrier reefs, unlike fringing reefs, a clearer ecological zonation of coral communities was established. The change of conditions on shelf edge with continental slope causes the barrier to appear, creating great variability in the ecological environment in front of, above, and behind it. Therefore, certain communities of Scleractinia were ascribed to the different elements of the underwater relief (continental slope, outer slope, outer edge, reef flat, lagoon slope) (Fig. 1.4). All of them were found in the complexes "which correspond to homogeneous conditions: morphological, hydrodynamic and sedimentological, bionomic" (Battistini et al. 1975, p. 25). The following complexes were established in the barrier reef: prelitoral, front reef, epireef, and postreef (the last two were absent in fringing reefs). The creation of complexes was based on the particularities of the reefs—the only community in the physical, geographical, and organic environment. Therefore, despite being defined according to the particular types of reef formation (near the island of Madagascar), complexes also occur in Caribbean waters. Local conditions of Cuban waters prepared the subdivisions of the complexes described here as zones with their corresponding communities (Fig. 1.4).

The continental slope creates a very asymmetrical ecological environment, because the rock on which the corals grow is very inclined, in some places almost steep and the sun's rays barely shine there. This favored the growth of flat colonies, laterally affixed to the rock by one of their ends, with their distal surfaces sticking out perpendicularly toward the penetrating light. The absence of active movements of water masses explains the fragility of the colonies and the decrease of food at that depth; it also explains the need for a wider area to capture food, i.e., a greater distance between individuals in the colonies. The growth of the colonies on thin plates is carried out, optimally, through serial intracalicinal budding. These are, then, the main characteristics of *Agaricia agaricites* forma *unifaciata*, whose colonies more frequently inhabited the continental slope. Thus, the community was named after this form. At times, the continental slope was completely covered by *Agaricia*. Next to it occurred *Helioseris cucullata*, *Mycetophyllia reesi*, *Mycetophyllia lamarckiana*, *Montastraea cavernosa*, *M. annularis auct.*, *Mussa angulosa*, *Scolymia lacera*, and others. When the continental slope was inclined or tiered, the community was not as homogeneous. We found sand and mud banks with coral knolls, as well as steep slopes with a greater presence of coral.

When the transition of the underwater relief, from the continental slope to the outer slope of the reef, was even steeper, the change in the scleractinian community was clear. Since the activity of the water masses on the outer slope was immense, the bottom was hardly slanted and well illuminated, and the environment was abounded with food. Thus, colonies were tightly attached, firm, massive, and quite often spherical; their diameter sometimes exceeded half a meter, reaching 2 and 3 m. When the bottom was rocky, it was greatly inhabited; when it was sandy, colonies are grouped around the first inhabitant that managed to attach itself, starting with the aforementioned knolls.

The active movement of water masses with abundant food particles was favorable both for scleractinians and all sessile filters. There were many octocorals and sponges. The growth of the sponges damaged the scleractinians because they lived on the coral colonies and killed the polyps. In some cases, their aggression caused a small but regular damage to the distal surface of the colonies. The morphological characteristics of the coralla varied as if another species had been found. This pathological phenomenon was conditioned by ecological factors having to do with the aggressor, not the coral. Therefore, in areas favorable to sponges, affected scleractinian colonies were more frequent. In other cases, the sponges of the *Cliona* genus penetrated the colonies, creating a thick network of small channels, destroying the coralla internally. Yet, mutualistic relationships with sponges were not always antagonistic; they could also be favorable for both parties, when some sponge species covered the lower surfaces of the coral colonies, so that the edges of the colonies could arch in an undulating way. In this case, the sponges had a larger habitable area, without competitors, and the feeding of the corals was facilitated by a strong water current caused by the sponges; furthermore, their lower surfaces were protected from the aggressive *Cliona* sponges.

In the limits of the external slope of the reef, two communities were established; the lower one occupied 95–99% of the width of the area, having greater specific diversity. Almost all species were found there, and their colonies were generally massive (spherical, cylindrical, bifacial, incrustation). It is difficult to point out a predominant species, which is why the area was called *Diploria–Montastraea*.

The part of the outer slope, below the outer slope, was almost always inhabited by *Millepora alcicornis* forma *alcicornis* and thus the name of the community. Scleractinia were rarely found.

The outer edge of the reef barrier is pounded by waves. The colonies of *Millepora alcicornis* forma *complanata*, with their fine vertical lamella, strongly welded together in polygonal constructions made up parts of the barrier and were the only attached animals that withstood the pounding of the waves and vibrations. The area was very narrow from 1 to 3–4 m and was only inhabited by these hydrozoans.

The reef flat is the shallowest area. The maximum depth does not exceed 60–70 cm. At low tide, the upper parts of *Acropora* were temporarily exposed. The width of the zone varied (from 30–40 to 150 m); it was inhabited by stable *Acropora palmata* colonies, enormous like trees (diameters: 1.5 m or more), sometimes welded together massively, which is where the name of the community was derived. These "forests" of acroporid coral were sometimes impassable. Sometimes, small colonies of *Favia fragum* and few spherical colonies of the species, known for inhabiting the outer slope, developed at their base. Also, there were isolated patios between *A. palmata*, totally inhabited by *P. porites* and areas covered by *Zoanthus*.

In some places, the reef barrier was crossed by channels, through which passed compensatory movements by water masses produced by local and tidal currents. Bottoms were excavated, rocky, and sometimes sandy with pebbles, and large, partially destroyed coral colonies. According to their active hydrodynamic nature, the channels were located at the bottom of the outer slope of the reef, with scarce inhabitants of the *Diploria–Montastraea* community.

The inner slope of the reef was the most protected area from the waves; it was a narrow strip of medium width from 5 to 20 m, inhabited by the community of dense bushes of "staghorn coral," *Acropora cervicornis* (thus the name of the community). In the same community also occurred *Favia fragum*, *Dichocoenia stockesi*, *Agaricia agaricites* forma *bifaciata*, *Mycetophyllia lamarckiana*, *Siderastraea radians*, *Mussa angulosa*, and others.

In the lagoon, we usually found fragmented and overturned colonies of *Acropora palmata* that managed to regenerate by continuing their growth, but in opposite directions, as if "their feet were facing upward." The presence of some colonies of *A. palmata* in the lagoon were indicative of the destructive force of past hurricanes. While the detritic sandy characteristic of the lagoon's sediments could be explained by the destructive force of the waves, the establishment of the oolitic sandy accumulations, for example, in the Archipelago of Los Canarreos, illustrated what caused the formation of oolite: there the coldest oceanic water mixed with warm lagoon water.

In the sandy "deserts" of the lagoon, knolls were made up of *Siderastraea*, *Diploria auct.*, *Meandrina auct.*, *Mycetophyllia*, *Dichocoenia*, *Montastraea auct.*, and others. Their diameter rarely exceeded 2 or 3 m.

The absence of a firm base caused incrustations to be more frequent in that area, which were usually the remains of other dead scleractinians, other organisms, and even pieces of different objects.

The most frequent inhabitant of the lagoon was the rose coral, *Manicina areolata*, which gave its name to the community. They "floated" at the surface of the muddy and sandy sediments, allowing their reproduction in this habitat. However, their growth was limited by their critical weight, when the coral "escaped" only with difficulty from the sediments. For this reason, this species and other inhabitants of the lagoon were dwarf sized as a result of pedomorphism.

In the lagoon, there were sometimes wide fields covered by *Thalassia* grass, often inhabited by the sea star *Oreaster reticulatus* and large gastropods. A part of the coral sand carried to the lagoon washed up to accumulate on the coasts, forming beaches or beach rock.

1.2.4 Reefs on Muddy Bottom

In the Gulf of Guacanayabo (Fig. 1.1), reefs with heights between 20 and 25 m grew on mud (now referred to as reticulate reefs—Zlatarski and Gonzáles Ferrer 2017; Zlatarski and Greenstein 2020) and were inhabited by species of Scleractinia that are not known as reef builders, such as *Oculina* spp., *Cladocora arbuscula*, *Madracis decactis*, *Porites porites* forma *divaricata*, and a new form of *Eusmilia fastigiata* with fine and small corallites. The colonies of *Acropora cervicornis* and the hydrozoan *Millepora alcicornis*, also usually found here, were smaller and more branched.

The geological conditions and hydrodynamic nature of the gulf, i.e., muddy bottom and almost motionless turbid waters, were all very unusual and contraindicative for the formation of contemporary reefs. The dimly lit, still, and turbid waters were unsuitable for a rich benthic community. With visibilities of only 20–30 cm underwater, we were able to verify that the vertical ridges of the reefs were made up of small, highly branched colonies of the genus *Oculina* (also called ivory coral) and *Cladocora arbuscula*; these were the only ones that, with their light, highly branched colonies, managed to take hold on the soft muddy bottom. The absence of competitors and the wide uninhabitable areas at the bottom made it possible for them to disperse greatly and, together with the exuberant increase of sponges, "weave" these paradoxical "gelatinous" reefs. This latter name arises from the fact that divers are able to move large portions of these reefs almost effortlessly due to the presence of sponges.

The body of these reef constructions was poor in specific diversity. No clear zonation or communities were apparent. In the upper part (depth of 2–5 m), the reef slopes were welded by a strip composed usually of *Acropora cervicornis*. The reef flat, with variable width (from 10 to 50 m), was often a desert covered by dead branches of *Oculina* spp., *Acropora cervicornis*, and *Porites* spp. or was heavily inhabited by *Thalassia* grass (these parts of the sea bed were locally known as “seibadal”). It is likely that the reef flat of the Gulf of Guacanayabo suffered serious destruction because of Hurricane Flora (1963). Often, “coral cemeteries” in this gulf recalled parts of the destroyed reef flat, covered in the Canarreos Archipelago or other Cuban reef locations, generally with the remains of *Acropora palmata*.

Less frequently, on the reef slopes in Guacanayabo, *Porites* spp., *Millepora alcicornis*, *Mussa angulosa*, *Mycetophyllia lamarckiana*, *Madracis* spp., *Siderastraea radians*, and *Eusmilia fastigiata* forma *guacanayabensis* occurred. The deviations in the morphology of gulf inhabitants were considered ecoforma and pedoforma, due to the specific hydrological and sedimentological conditions of this isolated area of the Cuban shelf.

Understanding this special type of reef is important not only for the most complete knowledge of the modern reef-formation process. The observation of a living model of reef construction on the soft muddy bottom holds special interest for paleontologists and lithologists, who often find reefs “standing” over clay, which were built by small, highly branched colonies.

1.3 General Review of the Ecology of the Scleractinians of the Cuban Archipelago

Figure 1.5 depicts the presence of scleractinians according to their profiles, stations, associations, communities, and their role in reef construction as observed in Cuba of the 1970s. Data on the left outline the total number of profiles where the taxon was found and then the number of profiles according to the type of reef where it was encountered (i.e., fringing reefs, barrier reefs, reefs in transition between the previous two, and reefs on muddy bottom). To a great extent, these values represent the frequency with which the taxa were found in the reefs.

Values on the right show the station in which each taxon was identified. First number is station and then number of stations according to the presence of the taxon in each association: present (found it locally), dominant (predominant of numbers or coverage of substratum, and highly dominant (predominant by more than half in numbers and coverage of substratum). Interestingly, only five taxa in 12 stations are highly dominant; 13 taxa are dominant in 52 stations; and all taxa are found as present.

The presence of each taxon in the community is expressed semiquantitatively: casual, constant, and characteristic of the community. “Characteristic” taxa are indicated when they make up the community entirely or $> 80\%$. These species tended to be absent or very rare when found outside this community. Among these were *Acropora cervicornis*, *Acropora palmata*, *Agaricia agaricites* forma *unifaciata, Manicina areolata*, and *Siderastraea radians*. In such cases, the communities are named after the characteristic taxon. An original case occurred with *Astrangia solitaria*, which independently and massively covered the dark walls of the coastal reefs. “Constant” taxa are indicated when a single taxon did not strongly predominate in the community and superiority is shared among some quite permanent ones. These include *Pseudodiploria strigosa*, *P. clivosa*, *Montastraea cavernosa*, and *Orbicella annularis*, for the outer slope of the fringing and barrier reefs. *Acropora palmata* and *Agaricia agaricites* forma *bifaciata* were constant in the fringing reefs as they moved away from the coast. The other taxa (casual) were present in the community. According to their specific diversity, the communities could be monotaxonic or polytaxonic. Communities were more differentiable on barrier reefs. With different fringing reefs, there were frequent deviations due to the nature of the coast; on muddy bottom reefs, the zonation was hardly visible and communities were not clear.

In the analysis of the morphology of the inhabitants of different communities, we note that the borders between them coincided with the *isophenes* (the lines that indicate the distribution of taxa of similar morphology). For example, in the barrier reefs in the lagoon, the inhabitants were most often nanoforms and pedoforms. The inner slope of the reef was inhabited by finely branched bushy colonies. The reef flat was covered by large, firm, tree-shaped colonies. The outer slope was “armed” with lamellar hydrozoans. On the outer slope, the most frequent were the spherical and bifacial representatives, and the continental slope was covered by fine monofacial colonies. The similarity in conditions caused the last two zones to be inhabited by the same scleractinians as in the fringing reef. Therefore, the isophenes in the two reef types coincided here. On the fringing reef, in the direction of land, finely branched shrub colonies appeared and then large colonies like trees. The absence of a barrier was the reason for the reverse distribution of isophenes in these parts of the fringing reef, in relation to barrier reefs.

A convergent development also occurred in the muddy bottom habitat. Only *Manicina areolata* and *Meandrina meandrites brasiliensis*, with conical coralla, were present on the soft bottom. They never grew to large dimensions. The first has been shown to have the ability to absorb water by decreasing its specific weight, thus helping it to “stand” and “come out” of the mud (Zlatarski 2018b, p. 96).

In accordance with their participation in reef building, the taxa were classified in four groups (Fig. 1.5): first-degree reef builders, second-degree reef builders, third-degree reef builders, and solitary participants.

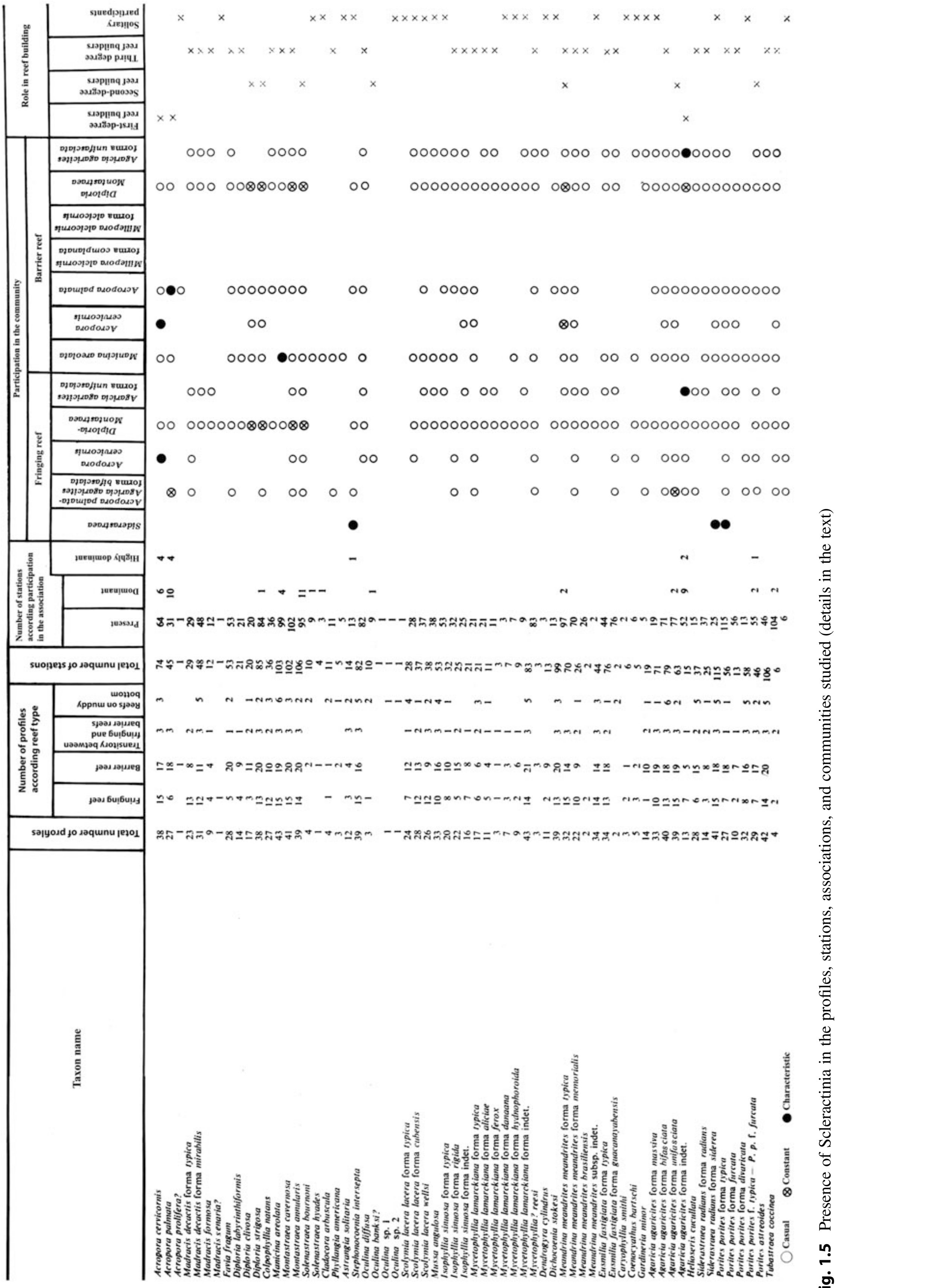


Fig. 1.5 Presence of Scleractinia in the profiles, stations, associations, and communities studied (details in the text)

By themselves, first-degree reef builders made up the reef body in complete zones; these were *Acropora cervicornis*, *Acropora palmata*, and *Agaricia agaricites* forma *unifaciata*.

Second-degree reef builders, together with others, played a decisive role in reef construction; these were *Diploria auct.*, *Montastraea annularis auct.*, *Oculina diffusa*, *Agaricia agaricites* forma *bifaciata*, and *Porites porites* forma *divaricata*.

Third-degree reef builders were often present in reefs, but because of their small size or quantity, they were not very significant in reef construction. It was possible for a taxon to be characteristic for a community but at the same time being a third-degree reef builder in the area (e.g., *Manicina areolata*).

Solitary participants were taxa in which one or some specimens have been found in the reefs or inhabit the rock caverns or caves. In such a group, we can even find a taxon characteristic for some community (e.g., *Astrangia solitaria*). Solitary participants usually had coralla with insignificant dimensions.

The composition of the associations was related to depth. Polytaxonic associations did not inhabit shallower areas (inner slope and reef flat), nor greater depths. The causes of monotaxonity and the exceptional richness of coralla closest to the sea surface and those living at great depth were different. In the former, this was linked to changes in depth. After the last glaciation, only *Acropora palmata* and *A. cervicornis* adapted to living at the highest parts of the reef. In the latter, this was due to the homogeneity of deep ocean environments and some unfavorable conditions.

The distribution of the Cuban scleractinians with depth in the 1970s is depicted in Fig. 1.6. Many of the Scleractinia inhabited greater depths than expected, but our research situation hindered our ability to study up to the inferior bathymetric limit.

The diversity of taxa at depths is shown in Fig. 1.7. Generic variability was hardly influenced by depth. Specific diversity varied sharply closer to the abscissas (20 m depth), unlike the variability of the representatives of the infrasubspecific category, whose numbers remained almost constant up to 30 m depth, and then decreased up to 60 m. Below this depth, the three curves were vertically oriented, that is, the number of taxa did not change.

Diversity was greatly controlled by the effects of urbanization near the water. Thus, for example, scleractinians rarely occurred in the waters off Havana at depths to 8–10 m. They did occur below this limit, up to 20 and 40 m and some at a depth of 55 m. For such cases, the so-called anthropogenic subclimax or disclimax was established.

Depth did not influence the distribution of the sciaphilic species. They were equally found at significant depth, as in caverns and dark caves or on the lower surface of other scleractinians. With an extremely photophobic characteristic, these were *Gardineria minor*, *Coenocyathus bartschi*, *Caryophyllia smithi*, and *Astrangia solitaria*. The colonies of *Tubastraea coccinea* were found in blocks of steep rocks and overhanging rock, i.e., they show less photophilia. This species was found only on the southeastern coast of Cuba. It is probable that it is a species that now quickly emigrates and has not yet settled in all Cuban waters. *Phyllangia americana* is the only species that inhabited very turbid and brackish waters.

1.4 Contemporary Perspective

The author started to study fossil Scleractinia in the Lower Cretaceous, finding rich localities in Bulgaria that urged massive phenotype collecting. The applied systematic sampling discovered rich biodiversity and many new taxa and proved to be the adequate way to study unknown material (Zlatarski 1968). This sampling strategy appeared reliable also for the investigation of modern Cuban scleractinians, because, since the first encounters with them, it became clear that some samples "did not fit in the drawers" of described discrete species and showed intermediate characters. It was evident that sampling should be the first decisive step for well-grounded coral taxonomic and ecological conclusions. The result was the largest Atlantic scientific stony coral collection curated and available now for study in the Acuario Nacional, Havana. It prompted leaving the typological species approach and led to the study of species dynamics. In addition, along with the stony corals, the associated organisms were collected, described, and curated (Martínez Estalella 1980, 1982, 2018).

The study is thoroughly explored by scuba all parts of the coral reef ecosystem accessible at that time. The underwater observations, collecting and profiling, were not regionally fragmented or limited to shallow reef zones (e.g., reef flat, front reefs). They were not stopped by the conventional doctrine, which pronounced that in tropical waters coral life disappeared deeper than 40 m (Cousteau and Diolé 1971, p. 268). The stony coral distribution and participation in reef formation received qualification, and Cuban scleractinians are continuing today to provide rich regional Caribbean information about the different zones of the coral reefs and about the upper part of the mesophotic zone, with no faunal break between shallow-water reefs and Mesophotic Coral Ecosystems (Zlatarski 1980, 1982, 2018a, b; Pyle and Copus 2019; see Chap. 14, Reed et al.).

The 1970 study covered the largest part of all zones of Cuban coral reefs ever to be the object of one project investigated using the same methodology. Regrettably, for some immense reefs, like the unique reticulated Gran Banco de Buena Esperanza in the Gulf of Guacanayabo, the information from that time is the only available, because it was never subsequently the object of stony coral investigation

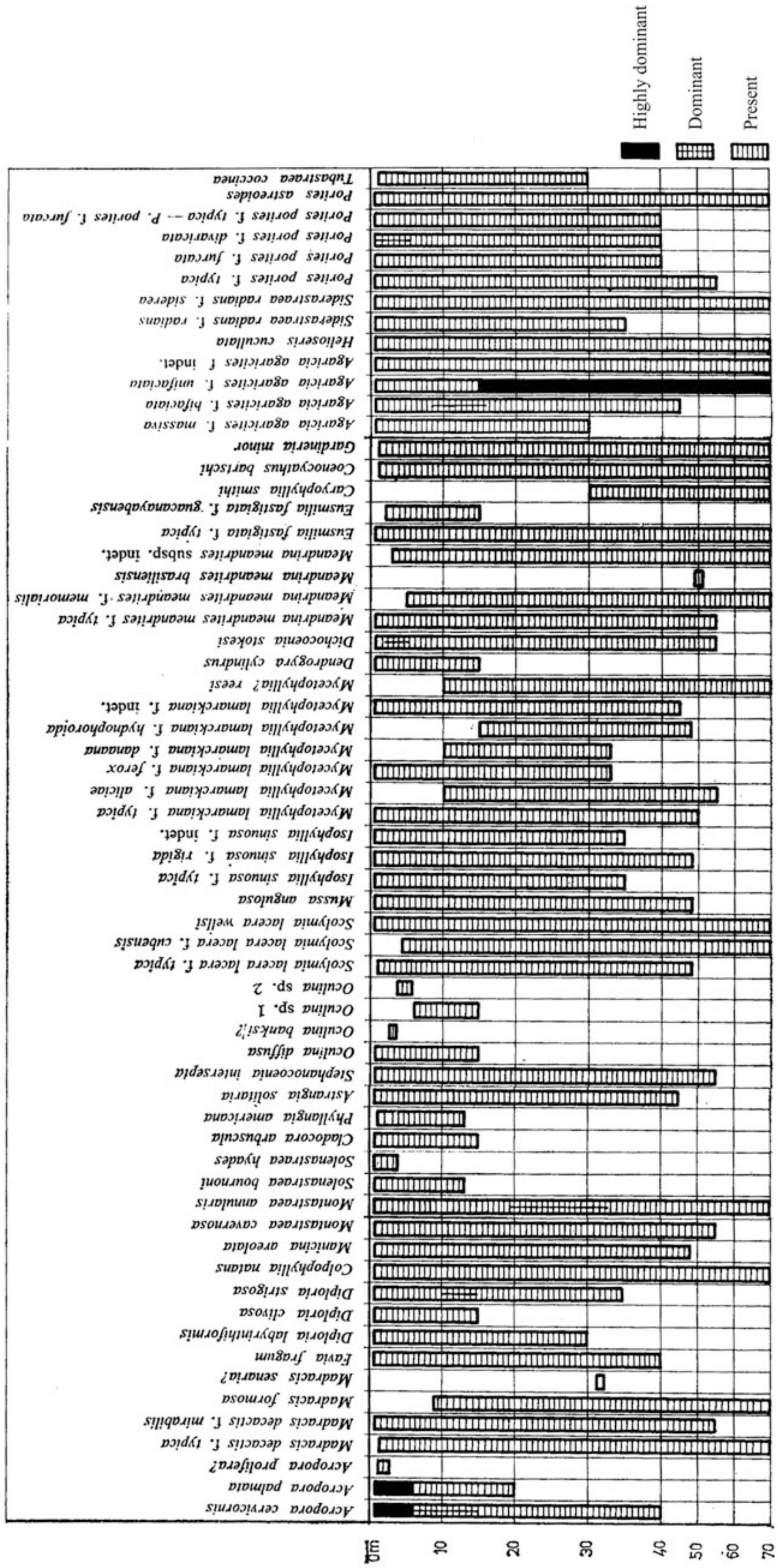


Fig. 1.6 Bathymetric distribution of Cuban Scleractinia

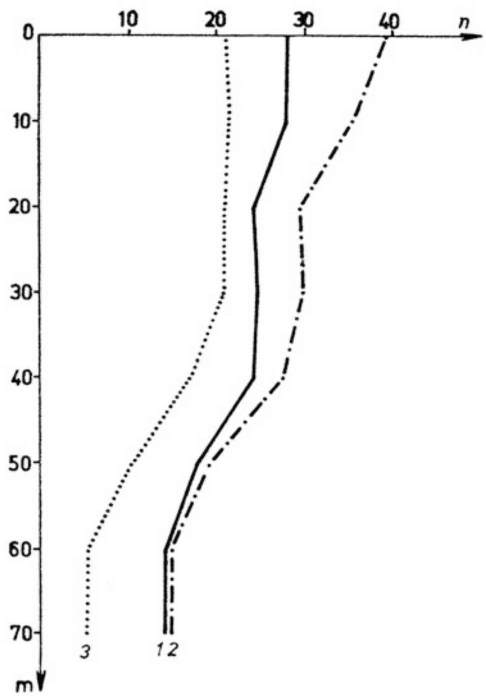


Fig. 1.7 Diversity of genera, species, and infrasubspecific categories in depth. 1 generic diversity; 2 species diversity; 3 infrasubspecífic diversity; *n* number of the taxa; *m* depth

(Hernández-Fernández et al. 2013; Zlatarski and Gonzáles Ferrer 2017; Zlatarski and Greenstein 2020).

The field work in Cuban waters was performed in maximal geographic and bathymetric ranges over a relatively short period (1970–1973), and as a result, the information produced provided a snapshot of Cuban coral reefs half a century ago. The past decades have brought considerable alteration of coral reefs with shift of zones and degradation. The 50-year-old documentation together with the physical collection itself offer a rare possibility for comparative studies and longtime ecosystem analysis. The data presented here from 1970 to 1973 from 44 profiles and 194 stations, together with the large coralla collection to a depth of 70 m and the scientific documentary, provide solid documentation of the status of reefs in the early 1970s (Zlatarski and Martínez Estalella 1980, 1982, 2018). As a result, today's researchers have solid older information at their disposal, and revisiting the documented places would offer the knowledge that is needed to support the conservation of the deteriorating coral reefs.

For example, in the 1970s, openly branching *Acropora* colonies with fused branches were rarely observed and always in the proximity of *A. palmata* or *A. cervicornis*. For these reasons, the species status of *A. prolifera* was treated with reserve and marked with a question mark (Zlatarski 1980, 1982, 2018b). Decades later, genetics proved that it is hybrid of both mentioned species (van Oppen et al. 2000). Interestingly, on a visit to Cuban waters during this century, the hybrid was observed more frequently, even in some lagoonal areas where its fragments formed the basis of buildups (Zlatarski 2010; Zlatarski et al. 2004). The opportunistic nature for potential survival of this scleractinian hybrid was proved by the fact that, since 1972, *A. prolifera* inhabits Gran Banco de Buena Esperanza with only one of its parents' species, *A. cervicornis*, and was evidenced by the presence of more than one F1 generation and its fertility (Zlatarski and Gonzalez-Ferrer 2017; Zlatarski and Greenstein 2020). The observed proliferation of the hybrid deserves special attention, especially in the present crisis in coral reef ecosystem, and any attempt to analyze the Caribbean acroporid corals by ignoring the established hybridization (Cramer et al. 2020) presents an incomplete picture.

In the early 1970s, the invasive species *Tubastraea coccinea* was found only on the southeast coast of Cuba (Zlatarski 1980, 1982, 2018b). Half a century later, it is present in different remote parts of the Cuban Archipelago–Canarreos Archipelago, northwest and north central coast (see Chap. 8, Gonzalez-Ferrer et al.). This urges study of the invasion process and the need for its control.

In the early 1970s, Cuban reefs were documented as a hot spot of scleractinian life in the Atlantic. Only few incidences of scleractinian abnormalities were observed—the presence of corallum hyperplasia, partial discoloration of the colonies, and damselfish chimneys—but not the existence of any epizootic phenomenon (Zlatarski et al. 2004). A clear negative urbanistic anthropogenic impact was documented in front of the Havana coast (Zlatarski 1980, 1982, 2018b). During the following decades, the reefs in Cuban waters underwent noticeable negative change, but the species richness remained high. There are ongoing serious efforts for reef conservation, which naturally should start with care for the reef-building coral species. In the Caribbean, the Cuban coral reefs are the largest, and they are centrally located, and the most diversified geographically and bathymetrically and with regard to bioconstructor zonation. The Cuban archipelago is only in part victimized by considerable anthropogenic deterioration. Some reefs are in good conditions. All of these factors make the Cuban reefs crucial for saving this threatened, vitally important ecosystem in the Caribbean. What is the best way to approach this goal? Many years of rambling in search of the most appropriate researcher's path lead to the highly Parnassian verse by Antonio Machado:

> Wayfarer, there is no way,
> you make the way as you go.
> (Machado 1982, p. 143)

Acknowledgments The manuscript benefited a great deal from the thoughtful constructive suggestions of the reviewer Bernhard Riegl. I also thank John Reed for the editorial improvements and Sergio González-Ferrer for his assistance with the figures. Also appreciated is the help of Dan Whittle, Valerie Miller, and Michael Pickard with the English translation of text previously published in Spanish.

References

Battistini R, Bourouilh F, Chevalier J-P, Condray J, Denizot M, Faure G, Fisher J-C, Guilcher A, Harmelin-Vivien M, Jauber J, Laborel J, Montaggioni L, Masse J-P, Mauge LA, Peyrot-Clausad M, Pichon M, Plante R, Plaziat J-C, Blessis YB, Richard G, Salvat B, Thomassin BA, Vasseur P, Weydert P (1975) Éléments de Terminologie Réciface Indopacifíque. Téthys 7(1):1–111

Cousteau J-Y, Diolé PH (1971) La vie et la mort des coraux. Flammarion, Paris

Cramer KL, Jackson JBC, Donovan MK, Greenstein BJ, Korpanty CA, Cook GM, Pandolfi JM (2020) Widespread loss of Caribbean acroporid corals was underway before coral bleaching and disease outbreaks. Sci Adv 6:eaax9395

Hernández-Fernández L, Olivera Y, González-De Zayas R, Salvat Torres H, Guimarais Bermejo M, Ventura Díaz Y, Pina-Amargós F (2013) Caracterización fisicoquímica e inventario de especies del Gran Banco de Buena Esperanza, golfo de Guacanayabo, Cuba. Rev Investig Mar 33(2):43–57

Machado A (1982) Selected poems (trans: Trueblood AS). Harvard University Press

Martínez Estalella N (1980) Data of organisms associated with Scleractinia of Cuba. In: Zlatarski VN, Martínez Estalella N (eds) The scleractinians of Cuba with data of associated organisms. Editions de l'Académie bulgare des Sciences, Sofia, pp 252–275. (in Russian)

Martínez Estalella N (1982) Données les organismes associés aux Scléractiniaires de Cuba. In: Zlatarski VN, Martínez Estalella N (eds) Les Scléractiniaires de Cuba avec des données sur les organismes associés. Editions de l'Académie bulgare des Sciences, Sofia, pp 401–435

Martínez Estalella N (2018) Datos sobre los organismos asociados a los escleractnios de Cuba. In: Zlatarski VN, Martínez Estalella N (eds) Los escleractinios de Cuba con datos sobre sus organismos asociados. Harte Research Institute for Gulf of Mexico Studies at Texas A&M University, Corpus Christi, pp 404–435. http://www.harteresearchinstitute.org/project/legacy-book-los-escleractinios-de-cuba-corals-cuba

Núñez Jiménez A (ed) (1970) Atlas Nacional de Cuba. Acad. Ciencia de Cuba, Acad. Cienc. URSS, La Habana

Pyle RL, Copus JM (2019) Mesophotic coral ecosystems: introduction and overview. In: Loya Y, Puglise KA, TCL B (eds) Mesophotic coral ecosystems, coral reefs of the world, vol 12. Springer, Switzerland, pp 3–27. https://doi.org/10.1007/978-3-319-92735-0_1

van Oppen MJH, Willis BL, van Vugt HWJA, Miller DJ (2000) Examination of species boundaries of the *Acropora cervicornis* group (Scleractinia, Cnidaria) using nuclear DNA sequence analysis. Mol Ecol 9:1363–1373

Zlatarski VN (1968) Paleobiology of the Urgonian Scleractinia of the Central Fore-Balkan. Dissertation, Geol. Inst., Bulg Acad Sci & Committee Geol, Sofia

Zlatarski VN (1980) The scleractinians of Cuba, Chapters 1–6. In: Zlatarski VN, Martínez Estalella N (eds) The scleractinians of Cuba with data of associated organisms. Editions de l'Académie bulgare des Sciences, Sofia. (in Russian)

Zlatarski VN (1982) Les Scléractiniaires de Cuba, Chapitres 1–6. In: Zlatarski VN, Martínez Estalella N (eds) Les Scléractiniaires de Cuba avec des données sur les organismes associés. Editions de l'Académie bulgare des Sciences, Sofia

Zlatarski VN (2010) Palaeobiological perspectives on variability and taxonomy of scleractinian corals. Palaeoworld 19(3–4):333–339

Zlatarski VN (2018a) Investigations on mesophotic coral ecosystems in Cuba (1970–1973) and Mexico (1983–1984). CICIMAR Oceánides 33(2):27–43

Zlatarski VN (2018b) Los escleractinios de Cuba, Capitulos 1-6. In: Zlatarski VN, Martínez Estalella N (eds) Los escleractinios de Cuba con datos sobre sus organismos asociados. Harte Research Institute for Gulf of Mexico Studies at Texas A&M University, Corpus Christi. http://www.harteresearchinstitute.org/project/legacy-book-los-escleractinios-de-cuba-corals-cuba

Zlatarski VN, Gonzáles Ferrer S (2017) Gran Banco de Buena Esperanza: unique Caribbean coral reef system. Reef Encounter 32(1):60–62

Zlatarski VN, Greenstein BJ (2020) The reticulate coral reef system in Golfo de Guacanayabo, SE Cuba. Coral Reefs 39(3):509–513. https://doi.org/10.1007/s00338-020-01933-7

Zlatarski VN, Martínez Estalella N (1980) The scleractinians of Cuba with data of associated organisms. Editions de l'Académie bulgare des Sciences, Sofia. (in Russian)

Zlatarski VN, Martínez Estalella N (1982) Les Scléractiniaires de Cuba avec des données sur les organismes associés. Editions de l'Académie bulgare des Sciences, Sofia

Zlatarski VN, Martínez Estalella N (2018) Los escleractinios de Cuba con datos sobre sus organismos asociados. Harte Research Institute for Gulf of Mexico Studies at Texas A&M University, Corpus Christi. http://www.harteresearchinstitute.org/project/legacy-book-los-escleractinios-de-cuba-corals-cuba

Zlatarski VN, Alcolado PM, González Ferrer S, Kramer P (2004) Archipiélago Jardines de la Reina, Cuba. Thirty years later, species richness of scleractinian corals remains high. Reef Encounter 32:30–32

Part II

History

2 Research History of Corals and Coral Reefs in Cuba

Sergio González-Ferrer

Abstract

This chapter summarizes the history of the scientific knowledge regarding Cuban coral reefs. The work of Antonio Parra, published in 1787, is the first book to refer to species of reef life in Cuba. In the nineteenth century, the works of Alexander von Humboldt, Charles Darwin, Ramón de la Sagra, Felipe Poey, and Rafael Arango are the most prominent, along with the debates on the origins of reefs by William O. Crosby and Alexander Agassiz. During the twentieth century, William M. Davis and William Smith considered the reefs on the southern coasts of Cuba to be the longest in the West Indies. Also in this century, multiple institutions devoted to marine studies emerged and research grew exponentially. The monograph by Zlatarski and Martínez Estalella, published in 1980, demonstrated the variety of the Cuban scleractinian and the presence of intermediate phenotypes of acknowledged species. Information is presented concerning "true" coral barrier reefs in Cuba, the contribution of projects such as AGRRA, the early warning voluntary monitoring in coral reefs, the studies of the mesophotic coral ecosystems, and the economic value of the Cuban coral reefs, with references to the most notable publications in the last 30 years.

Keywords

Coral reefs · History of coral reef science in Cuba · CIM · IDO · CITMA

S. González-Ferrer (✉)
La Habana, Cuba

2.1 First Traces of Interest in Corals and Coral Reefs

Great naturalists and worthy scientists have left their mark in the research of Cuban coral reefs. This chapter provides a summary of the main moments in the the discovery of knowledge on these ecosystems in the largest island of the Antilles. Reference is made to the publications of some of the different zoological groups that form these reef systems; however, according to Alcolado et al. (2003), "stony coral" and "coral reef" are terms necessarily and closely linked, at least when writing about their recent history.

We start off with traces of the first human settlements on the Isle of Cuba, where the coral reefs in some coastal areas represented good sites for fishing, harvesting, and sheltering from the actions of the waves. If we want to find the beginnings of interest in these ecosystems in Cuba or point to their discoverers, we must go back to the pre-agro-pottery (protoarchic) and agro-pottery groups who inhabited the coast of Cuba since 6000 years BC. Perhaps, the only proof of this are the anthropomorphic figures, seemingly of a religious nature, funerary objects, or possible mortars, used to macerate foods or ritual substances, prepared by those cultures from stony corals (González-Ferrer 2004a, Fig. 2.1).

2.2 The Eighteenth Century: The "Interesting Stones" of Don Antonio Parra

In the eighteenth century, we find the first evidences of scientific curiosity regarding some of the organisms belonging to coral reef ecosystems. Cuba had only around 171,620 inhabitants (ONEI 2019) which begin to open up to the Enlightenment, a philosophical, artistic and scientific movement coming from Europe. According to García Sanchez (2011), this movement considered reason as the only force capable of ensuring progress, and, at the same time, its

V. N. Zlatarski et al. (eds.), *Coral Reefs of Cuba*, Coral Reefs of the World 18, https://doi.org/10.1007/978-3-031-36719-9_2

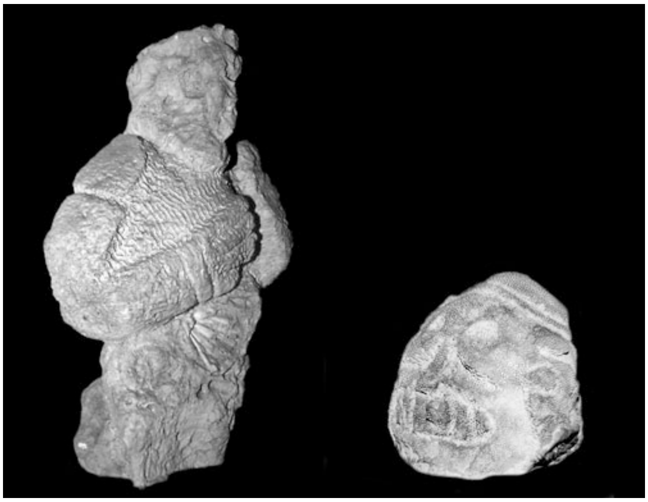
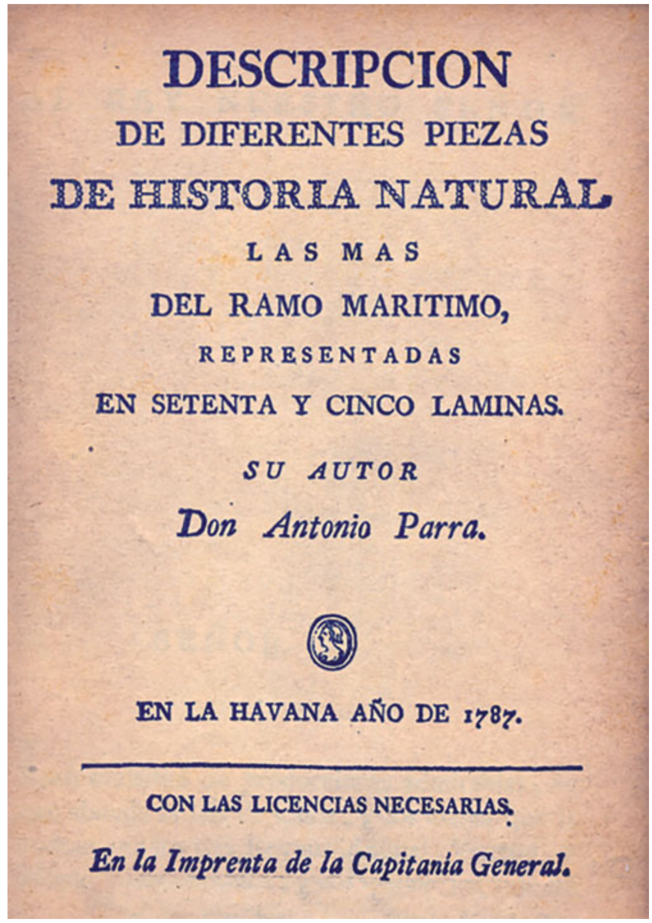


Fig. 2.1 Idols sculptured on stony coral by natives in the Cuban isle. These pieces can currently be found in the Museo Antropológico de la Universidad de La Habana (Anthropological Museum of the University of Havana)

defenders felt a great love for nature and a preference of useful things over beautiful ones. In Garcia's (1859) opinion, it is with the establishment of the Real y Pontificia Universidad de San Gerónimo de La Habana in 1728 and the Colegio de la Compañía de Jesús around the same time that the Cuban Enlightenment had its beginnings.

It is in this atmosphere of thought and with the end of the war of 1763 between Spain and England that Don Antonio Parra Callado, of Portuguese origin, arrived in Cuba as a simple soldier of the Mallorca infantry regiment at the order of King Carlos III. He soon retires from the army and forms a family, while his interest for natural history leads him to gather collections, especially of "marine productions" (García 2016). The publication *Descripción de Diferentes Piezas de Historia Natural las mas del Ramo Maritimo, Representadas en Setenta y Cinco Laminas* (Description of Different Pieces of Natural History most of them of the Marine Branch, Represented in 75 Pictures) by Parra (1787) constitutes the catalog of his collection (Fig. 2.2).

This book was published by the Imprenta de la Capitanía General (General Captaincy Press) in Havana and is the first in Cuba to be illustrated with engravings of the collections made by hand by the author's son on copper etching, with a layer of wax over the metal (Saco 1858a; García 2016). Those collections came from the coasts, fishing nets, and limestone quarries from which material for colonial constructions were extracted, as well as from the Escambray Sierra. Parra groups in this collection and in his later work 71 species of fish and 25 crustaceans, many of them of reef life, besides reptiles and a considerable number of species of echinoderm, sponge, gorgonian, algae, polychaete, as well as stony coral, which he calls "interesting stones" (González-Ferrer 2004a, Fig. 2.3).



DESCRIPCION
DE DIFERENTES PIEZAS
DE HISTORIA NATURAL
LAS MAS
DEL RAMO MARITIMO,
REPRESENTADAS
EN SETENTA Y CINCO LAMINAS.
SU AUTOR
Don Antonio Parra.

EN LA HAVANA AÑO DE 1787.

CON LAS LICENCIAS NECESARIAS.
En la Imprenta de la Capitania General.

Fig. 2.2 Cover of Don Antonio Parra Callado's book (1787)

All of these exhibits, identified by their popular names, constituted the first Science Cabinet of Havana (Presas 1866) which, because of its frequent public exhibition, could be considered the main predecessor to the natural science museums of Cuba. Parra's collection later traveled to Spain to form part of the Royal Cabinet of Natural History, for which King Carlos IV assigned him a tidy annual pension (Parra 1799). Some of the specimens of this collection are still kept in the Museo Nacional de Ciencias Naturales de Madrid and maintain their "original" shape and color (García 2016).

Years later, several scholars set themselves to classifying Parra's exhibits, a work that can be considered among the first classification of Cuban reef-life organisms. Thus, the Spanish geographer and naturalist Don José Cornide, one of the better-known members of the Enlightenment in Galicia, made a classification of several of the fishes, which was later amended by Saco (1858a). Similarly, the French sages Georges Cuvier and Achille Valenciennes, in their publication *Histoire Générale et Particulière des Poissons*, assign scientific names to Parra's common names (Jimeno 1858), not without some errors corrected later by the Cuban scholar

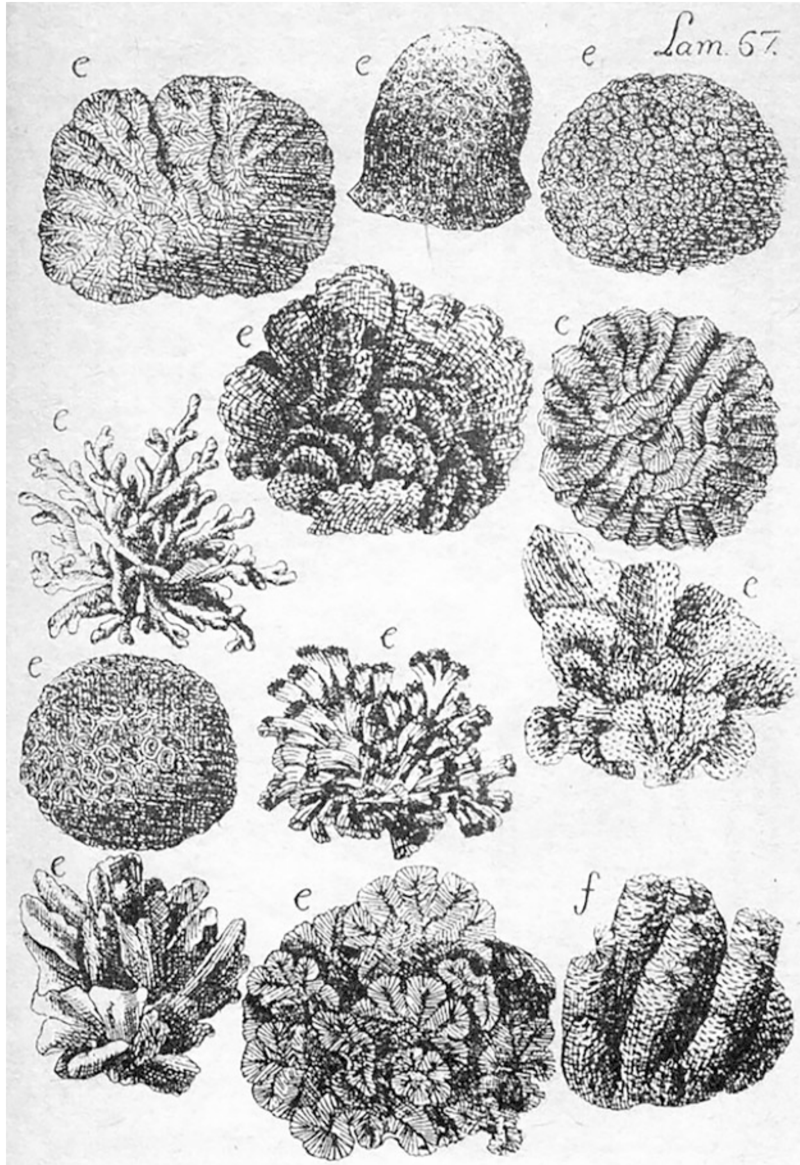


Fig. 2.3 Some “interesting stones” published by Parra (1787)

Felipe Poey y Aloy in his work *Enumeración de los Peces Descritos y Figurados por Parra (List of the Fishes Described and Illustrated by Parra)*, published in the Proceedings of the Philadelphia Academy in 1863 (García 2016). Presas (1866) tells us how French zoologist Henri Milne-Edwards used Parra’s data of crustaceans in his publication Historia Crustacea of 1837. In addition, the Frenchman Guérin-Méneville (1856), the great German scientist resident in Cuba Juan Gundlach in 1917 (García 2016), and more recently Sanchez-Valero et al. (2009) classified some echinoderms, one annelid, one bryozoan, some sponges, and two corals. However, among these latter “interesting stones,” it is not difficult to distinguish Parra’s drawings at least five genus (González-Ferrer 2004a).

Parra’s book is undoubtedly a scientific relic (Fernández 1943) and contains the first noteworthy approximation to Cuban coral reefs, although as Parra himself said concerning his collections “serving as a sample, they will make the lion known by its nail.”

2.3 The Nineteenth Century: Beginnings of Marine Sciences in Cuba

The nineteenth century begins with the visits to Cuba by Alexander von Humboldt in the years 1800 and 1804. This German explorer and scientist is considered by many as the second discoverer of the Americas, given his extensive and varied work in these lands and because, according to Acosta (2005), he did not have the biased colonialist view of many European scholars. In his work *Political Essay on the Island of Cuba* published in 1826 (Fig. 2.4a, b), he refers to reefs