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Tropical Coast of Brazil

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This provides a general overview of the tropical coast of Brazil, with emphasis on the marine realm. The described region extends for approximately 3000 km, and has three different sectors (northern, north-eastern and eastern), each one with distinctive characteristics.

The north and north-east sectors have a predominantly semi-arid climate, whereas the eastern sector is tropical and humid. North-easterly trade winds occur mostly in the north sector, but in the north-east and east sectors south-easterly and easterly trade winds are more important. Three factors controlled sedimentation along the coast of tropical Brazil during Late Quaternary time: the sea-level history that played an important role in the evolution of the coastal zone and its related ecosystems over the last 5000 years; a sediment supply that is primarily regulated by the local relief and climate; and the climate itself, which is the major controller of the large and active dune fields found in the northern sector.

Coral reefs are one of the most prominent marine ecosystems of tropical Brazil, particularly because of the unique character of its low-diversity coral fauna which is rich in endemic species; it is a relic fauna from the Tertiary, which forms unusual mushroom-shaped coral pinnacles. They include the southernmost coral reef communities of the Atlantic, and a small atoll.

A transition from siliciclastic dominant sediments on the coastline, to pure carbonates toward the middle and outer shelves, characterizes the continental margin of tropical Brazil. Human development was generally low until recently due to lack of roads and infrastructure, but new development has led to expansion in the area. Uncontrolled urban development, associated with heavy industrialization and consequent pollution – uses which are not appropriate for these coastal marine ecosystems – and the accelerated deforestation of the Atlantic Rainforest are, today, the major threats to the tropical Coast of Brazil.

The Region

The tropical coast of Brazil extends from the Maranhense Gulf (2°00′S) to the Paraíba do Sul coastal plain (21°50′S) (Fig. 1). It comprises three sectors: the northern (2–5°S), the north-eastern (5–12°S) and the eastern sectors (12–21°S). There are three major geomorphologic provinces within these regions:

1. A Precambrian basement hinterland dominated by rounded hills, with altitudes varying from 50 to 500 m.
2. The Tablelands: this is the most important and extensive morphological unit, almost continuously bordering the shoreline. These have an extremely flat surface with deeply incised flat-bottom valleys. This area is comprised of unconsolidated Late Tertiary alluvial sediments, mostly debris flow deposits, but also including fluvial channel and lacustrine deposits, the Barreiras formation. This represents an important reservoir of sediment to the coastal zone, particularly in those regions where active sea cliffs are present.
3. The Quaternary plain: Quaternary deposits of various origins (beach-ridge plains, wetlands and coastal dune fields) are distributed discontinuously along the shoreline and separated from the Tablelands by a line of fossil sea cliffs.

The continental shelf, in tropical Brazil, varies considerably in shape and width. It is mostly very narrow, an average width of 50 km. In the southern section the shelf widens, particularly in the Abrolhos Bank region (see Fig. 1), as a result of damming of sediment by volcanic seamounts. The shelf break is located at an average depth of 80 m. Sedimentation in the inner shelf, up to a depth of 20 m, is dominantly siliciclastic. In the middle and outer shelves carbonates dominate, except near major rivers where siliciclastic sedimentation can reach the outer shelf. Terrigenous mud accumulation is also restricted to these areas (Milliman and Barreto, 1975). Carbonate mud is locally deposited on the offshore inter-reefal zones.

Oceanographic Parameters

Coastal climate

The general atmospheric circulation pattern is controlled by two elements (Bigarella, 1972): (i) air masses generated in the South Atlantic high-pressure cell and (ii) advances of polar air masses. The South Atlantic is devoid of hurricanes, so only the above two elements,

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Fig. 1 Map of the coastal area of tropical Brazil.

associated with the Intertropical Convergence Zone, define climate here. The north-eastern and eastern coasts are therefore dominated by the south-easterly and easterly trade winds, whereas in the northern coast, north-easterly trades prevail. Along the eastern coast, a divergence zone of the trade winds occurs and north-eastern winds blow to the south of this zone. A seasonal variation in the position of the South Atlantic high-pressure cell produces a north–south oscillation of the divergence zone between 10° and 20°S. This zone moves northward during summer and southward during winter. As a result, easterly and south-easterly winds dominate the coast north of 13°S, year-round, with speeds ranging from 5.5 to 8.5 m/s (US Navy, 1978). South of 13°S, the easterly and south-easterly winds blow during fall and winter (April–September) and the north-easterly winds prevail during spring and summer (September–February); in this area, the wind speed rarely surpasses 5.5 m/s (US Navy, 1978). The Antarctic polar front moves northward across the South American continent, east of the Andes Mountains as great anti-cyclones and splits into two branches. The eastern branch moves along the coast towards the Equator and can reach as far as 10°S during winter but rarely reaches latitudes lower than 15°S in summer (Dominguez *et al.*, 1992). The advance of this polar front also generates additional south–south-easterly winds, which reinforce the south-easterly winds generated by the anti-cyclone high-pressure cell. Gale force winds (25 m/s) have been measured along the advance of these polar fronts (Bandeira *et al.*, 1975).

Climate in the north–north-eastern coast of Brazil is classified as semi-arid, whereas in the eastern coast it is of the tropical humid type. The coastal zone from

4° to 6°S has at least four to five dry months during the year (Nimer, 1989). This extended dry season has favoured extensive dune development in this part of the coast.

Sea-surface temperature (SST) is the most conservative parameter along the Brazilian tropical coast, varying in the north–north-eastern coast from 30°C during summer and fall (February–May) to 28°C from the end of winter to the beginning of summer (August–December). In the eastern coast, SST varies from 30°C (February–May) to 27°C (July and August). Minimum temperature, however, shows a marked decrease from north to south. On the north–north-eastern coast, it decreases from 25°C during summer and fall, to 23°C during winter and spring; on the eastern coast, during winter, the minimum temperature can reach as low as 21°C (US Navy, 1978).

The wave pattern is conditioned by variation in the trade winds, and is related to movements of the offshore high-pressure centres. The Brazilian coast is mainly dominated by sea waves (locally generated waves with periods less than 7 s), and those with heights above 1 m account for more than 50% of observations (US Navy, 1978). These are the kinds of waves that Larcombe *et al*. (1995) found to be more effective in increasing turbidity of water in their four months of measurements, near the city of Townsville, Australia. In the Brazilian northern and north-eastern coasts, the NE and E–SE waves dominate year round, with the eastern waves more important from January to May (summer–fall) and from September to November (spring). The southernmost part of the north-eastern coast and the eastern coast, on the other hand, are dominated by eastern waves during the whole year. North-east waves are only important from November to February (summer), whereas south-east waves occur from March to August (winter).

Tides on the continental shelf are semi-diurnal. Due to the large latitudinal extent of the shelf, two different areas are defined (Hayes, 1979): (i) upper mesotidal in the northern and north-eastern coasts and (ii) lower mesotidal to microtidal in the eastern coast. The most conspicuous effect of the tidal component is observed in the northern coast, where it enhances the north-westward flow of the Brazilian Current (BC) (the North Brazilian Current (NBC)) and periodically produces an intensification of this drift.

The BC and the NBC are the main surface currents on the Brazilian continental margin (Stramma, 1991; Silveira *et al*., 1994). They originate from the South Equatorial Current at about 5–6°S and flow south (BC) with an average velocity of 50–70 cm/s, and to the north and north-west (NBC) attaining velocities of 30 cm/s. Data from the Atlas de Cartas Piloto (DHN, 1993) show that between 10° and 13°S, during July and August (austral winter), a reverse flow to the north can occur. North of 5°S, the NBC becomes stronger as a result of combining with the South Equatorial Current.

Sedimentation

Major controls on sedimentation along the coast and in the adjacent continental shelf include sea-level history, sediment supply and climate.

Two important transgressive episodes affected the coastal zone during the Late Quaternary (Dominguez *et al*., 1992): (i) the Penultimate Transgression, which reached a maximum of 8 ± 2 m above the present level around 123 000 years BP and the Last Transgression, which reached a maximum about 5100 years BP, when sea level was positioned 5 ± 2 m above the present sea level. This sea-level history has played a pivotal role in the evolution of the coastal zone and its ecosystems during the last 5000 years. During the maximum of the Last Transgression most of the coastal zone was inundated. Estuaries, bays, lagoons and barrier islands were the most important coastal environments rivers drained into these and not directly into the open ocean. This was the time of maximum expansion of the mangrove forests and of optimum development for coral reefs on the adjacent shelf. During the following drop in sea level, vast areas of estuaries and lagoons disappeared and reef tops were exposed. Progradation of the shoreline, as a result of increased sediment supply from rivers and the drop in sea level itself, brought the shoreline and the coral reefs close together, or simply buried them with siliciclastic sediments. Increased turbidity resulted in additional stress to coral reefs and other inner shelf ecosystems.

Sediment supply varies considerably along Brazil's tropical coast and is controlled by area, relief and climate (Dominguez and Bittencourt, 1996). The rivers emptying into the coast between São Francisco to the Paraíba do Sul river mouths are characterized by drainage basins that are larger, have higher mean altitude and wetter climate than along the coast between the São Francisco river mouth to the Maranhense Gulf. These differences in sediment supply are reflected directly in the distribution of Quaternary deposits along the whole coastal zone (see Fig. 1). Quaternary deposits resulting from progradation of the shoreline are abundant, south of the São Francisco River mouth, whereas north of this river the tablelands reach the present day shoreline, forming active sea cliffs.

Besides its effect on the sediment supply to the drainage basins, in the coastal zone itself climate controls the distribution of Eolian deposits. In Tropical Brazil, active coastal dunes are restricted to those areas where more than three consecutive dry months occur during a year. These conditions are met along the northern coast, where large dune fields are present. The Lençois Maranhenses dune field (Fig. 2) is the largest

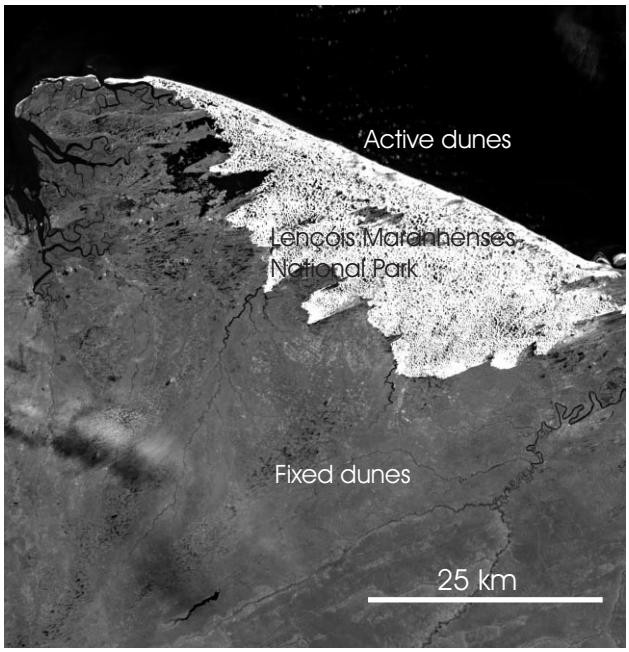

Fig. 2 Satellite image illustrating the Lençois Maranhenses on the northern sector of the tropical coast of Brazil.

coastal dune complex in the entire South American continent.

Major Marine Habitats

Continental shelf

Carbonate sediments dominate the entire tropical Brazilian middle and outer shelves. Bioclastic carbonate gravel and sands (free-living non-articulated coralline red algae – maërl – *Halimeda*, benthic Foraminifera and mollusc debris), are also an important constituent in the inner shelf in many areas of the shelf (Coutinho, 1980; Dominguez and Leão, 1994; Testa, 1997; Testa and Bosence, 1998, 1999). More commonly, the inner shelf is a typical mixing zone of siliciclastic and carbonate sediments: the former from river discharges, coastal erosion and lower-sea-level stands and carbonates from in situ growth and transport of calcareous organisms, such as red and green algae. Near the São Francisco River mouth (10°30′S), the largest river on east–north-eastern Brazil, the carbonate sediment production is interrupted, probably due to water turbidity (Tiltenot *et al.*, 1994). Also, the inner shelf of the eastern sector region, between the Jequitinhonha (15°00′S) and Doce (19°40′S) rivers, is influenced by river discharges and here plumes of fine sediments are seen to advance some 50 km offshore. In these areas, bioclasts occur only on the middle and the outer shelves and the main carbonate sediments are mollusc shells, benthic Foraminifera tests, debris of calcareous algae, bryozoans, echinoids and, more rarely, coral gravel. Coral reefs occur along most of the carbonate province.

Coral Reefs

The Brazilian coral reefs form structures significantly different from most of the well-known coral reef models in the world, as (i) they have a characteristic initial growth form of mushroom-shaped coral pinnacles, (ii) they are built by a very low-diversity coral fauna, rich in endemic species and in which major reef builders are archaic forms, remnant of an ancient coral fauna dating back to the Tertiary, (iii) encrusting coralline algae has an important role in the construction of the reef structure and (iv) the nearshore bank reefs are surrounded and even filled with muddy siliciclastic sediments. Thus they are a reef ecosystem ecologically unique and are, also, economically valuable for fisheries and ecotourism.

The reefs are formed by the coalescence of isolated columns called chapeirões that grow from the bottom of the ocean in a mushroom-like shape; their base is narrow and the top expands laterally. There are chapeirões of different heights and widths, in widely diversified stages of growth. When they are closely spaced, which usually occurs in reefs nearest to shore, adjacent chapeirões fuse together at their tops, forming large compound reef structures called bank reefs, which have horizontal tops, are somewhat irregular, and which can become completely uncovered during low tides. In these intertidal reef flats, large coral heads are truncated by erosion, and they alternate with numerous small pools, some shallow and sandy, but others rather deeper and with rocky bottoms. Irregular meandering channels of varied depths connect these pools with surrounding waters.

Corals, millepores and coralline algae build the rigid frame of reefs in Brazil. The coral fauna comprises 18 species, almost half of them endemic to Brazilian waters (Belém *et al.*, 1986). Among these endemic species some have affinities to the Miocene European corals and some are related to the Eocene Caribbean species (Laborel, 1969a,b). These archaic species were preserved during Pleistocene low stands of sea level, in a refugium provided by the sea mountains off the Abrolhos Bank (Leão, 1982). Three milleporids and one stylasterid (Laborel, 1969a; Hetzel and Castro, 1994) represent the hydrocorals. The Brazilian hermatypic corals and hydrocorals were first described in the last century by Verrill (1868), later by Laborel (1969a,b) and more recently have been examined in some detail (Amaral, 1994; Amaral *et al.*, 1997; Castro, 1994; Echeverría *et al.*, 1997; Maÿal and Amaral, 1990; Pires *et al.*, 1992; Pitombo *et al.*, 1988; Villaça and Pitombo, 1997).

Brazilian reefs can be grouped into various reef types: (i) nearshore bank reefs that comprise small discontinuous reef structures, adjacent to the beach and of variable but often elongate forms; (ii) isolated bank reefs off the coast, of widely variable sizes ($\ll$10 m to $\gg$20 km) and shapes (elongate, circular, semi-arched), which, due to the lateral discontinuity of their structures, are different from the classical examples of barrier reefs;

(iii) fringing reefs, more or less continuous, formed by encrustation of calcareous organisms on the rocky outcrops that usually occur bordering the coast of islands; (iv) isolated open-sea coral pinnacles, which are giant chapeirões growing from the bottom and which can reach the sea surface; (v) superficial reefs that are coral–algal constructions of no great thickness developed mostly above lines of beach rock; (vi) one small atoll and (vii) drowned reefs.

These reefs are distributed into three major sectors along the tropical coast of Brazil. The northern coast apparently contains only one coral bank, 18 km long by 6 km wide, called Parcel de Manuel Luis, located about 80 km off the coast of São Luiz (State of Maranhão) and monospecific coral aggregates that occur along the coast of the state of Ceará (Coura, 1994; Laborel, 1969a,b; Maida and Ferreira, 1997). The north-eastern coast has several types of reef structures: (i) Rocas atoll located 267 km off the coast of Natal (Rio Grande do Norte State), (ii) coastal isolated bank reefs of varied shapes and dimensions forming one, two or three lines of reefs along the coast of the states of Rio Grande do Norte, Paraiba, Pernambuco and Alagoas and which may be associated with lines of beach rock and (iii) coral constructions bordering the shores of the oceanic islands. Examples are seen in the Fernando de Noronha Archipelago, about 345 km east off the coast of Rio Grande do Norte, in the São Pedro and São Paulo Archipelago about 500 km north-east from Fernando de Noronha (Kikuchi and Leão, 1998; Laborel 1969a,b; Maida and Ferreira, 1997; Pires *et al*., 1992; Secchin, 1986; Testa, 1996, 1997) and off the eastern coast in three different sectors of the state of Bahia (see Fig. 1).

North of Salvador City, discontinuous coral bank reefs occur for about 20 km in very shallow waters; superficial coral–algal reefs, with thickness of less than 1 m, developed above a line of beach rock and drowned reefs occur in depths ranging from 20 to 70 m (Kikuchi and Leão, 1998; Leão, 1996; Leão *et al*., 1988, 1997; Nolasco and Leão, 1986). In the Todos os Santos Bay, shallow fringing reefs, more or less continuous, border islands (Araujo *et al*., 1984; Leão, 1996; Leão *et al*., 1988).

Southern Bahia contains the largest and the richest area of coral reefs along the entire Brazilian coast. Its northern part is the least known area, but fringing reefs border the shores of islands and of Camamu bay. These reefs are more or less continuous structures, whose tops become completely exposed during low spring tides (Leão, 1996). North to the Abrolhos Bank, small bank reefs, with varied shapes and dimensions, may have grown on submerged strings of beach rock at about 10 m, but southward, where the continental shelf widens, forming the Abrolhos Bank, is the largest and richest coral reef area of Bahia (Fig. 3). These reefs form two arcs: a coastal arc located a few kilometres from the coastline is composed of bank reefs of varied shapes and dimensions and an outer arc bordering the east side of the Abrolhos Archipelago, formed by isolated chapeirões in water deeper than 20 m. Incipient fringing reefs border the shores of five islands that form the Abrolhos Archipelago (Castro, 1994, Leão, 1982, 1994, 1996; Leão and Ginsburg, 1997, Leão *et al*., 1988, Pitombo *et al*., 1988).

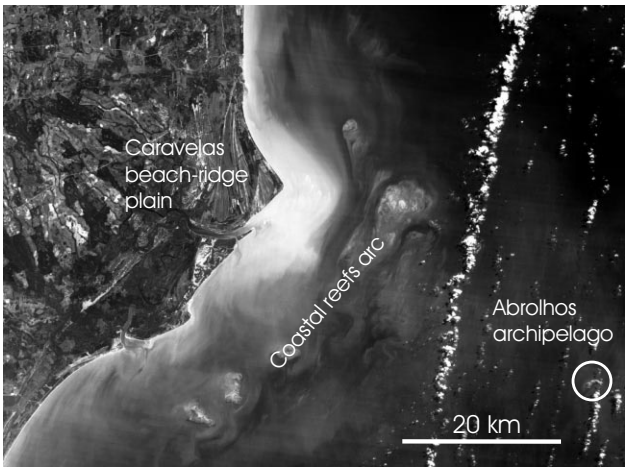

Fig. 3 Satellite image of the eastern sector of the tropical coast of Brazil illustrating the Caravelas beach-ridge plain and the Abrolhos coastal reefs.

Bays

Todos os Santos Bay is the biggest and the most important bay in the entire tropical coast of Brazil (Fig. 4). Its structure is inherited from an aborted-rifted basin formed during the South America–Africa separation, in

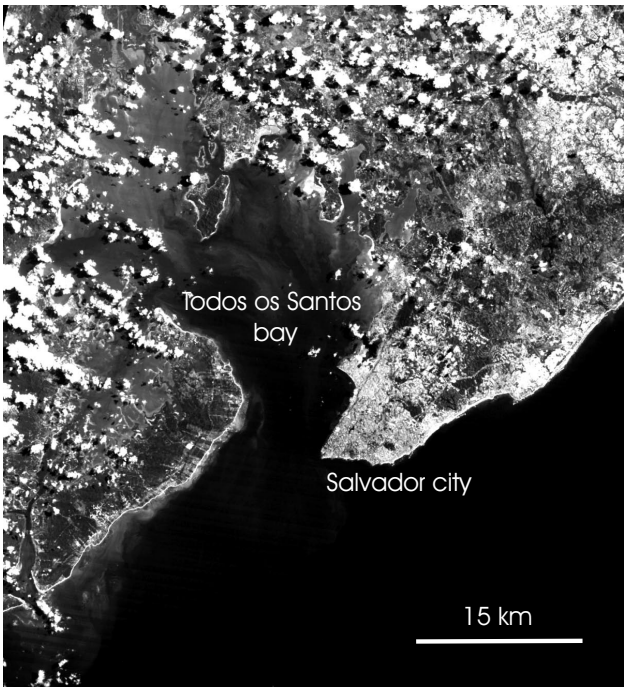

Fig. 4 Satellite image of Todos os Santos Bay at the eastern sector of the tropical coast of Brazil.

Cretaceous Time. It contains about 35 islands and although the bay receives about 200 m^3/s, of freshwater drainage, this volume is two orders of magnitude less than the estimated volume of tidal water that enters through the main bay opening; its characteristics are clearly marine (Lessa *et al.*, submitted). Muddy bottom sediment predominates in the northern portion, whereas its southern portion has an accumulation of medium to very coarse sands. Bioclastic sediments cover large areas of the bottom. Since its discovery in the sixteenth century, the bay of Todos os Santos has been heavily used, from mining of calcareous sands, to petroleum exploration, overfishing, industrial sewage and intensive tourism.

Major Coastal Habitats

The Atlantic Rainforest (The Maritime Forest)

When Portuguese settlers arrived in Brazil, the Atlantic Rainforest covered an area of about 1 million km^2, or 12% of the Brazilian territory. Today, this forest is reduced to 5% of its original distribution. In tropical Brazil, the most important remnants of this maritime forest are located in the southern part of the State of Bahia, between the Jequitinhonha and the Caravelas strandplains (Fig. 5). The great majority of the Brazilian flora and fauna, which are listed as endangered species, are endemic to this Atlantic Rainforest.

Restinga

This term is used in Brazil to describe the biological communities that thrive in sandy coastal deposits (dunes and beach-ridge plains) accumulated as a result of shoreline progradation. The vegetation, comprised of grasses, shrubs and small trees, is adapted to soils that are virtually devoid of nutrients and they exhibit xeromorphic characteristics allowing them to survive in this relatively dry sandy substrate. The salt spray is their most important source of nutrients. The most important Restinga in tropical Brazil are associated with the most prominent beach-ridge plains, such as the São Francisco, Jequitinhonha, Caravelas, Doce and Paraíba do Sul (Fig. 6) strandplains.

Wetlands

Wetlands are very limited in tropical Brazil. Freshwater wetlands are restricted to flat-bottom valleys incised in the tablelands, or occur in low-lying areas in the Quaternary plains, which acted as coastal lagoons during the maximum of the last Transgression. In these freshwater wetlands, emergent vascular macrophytes

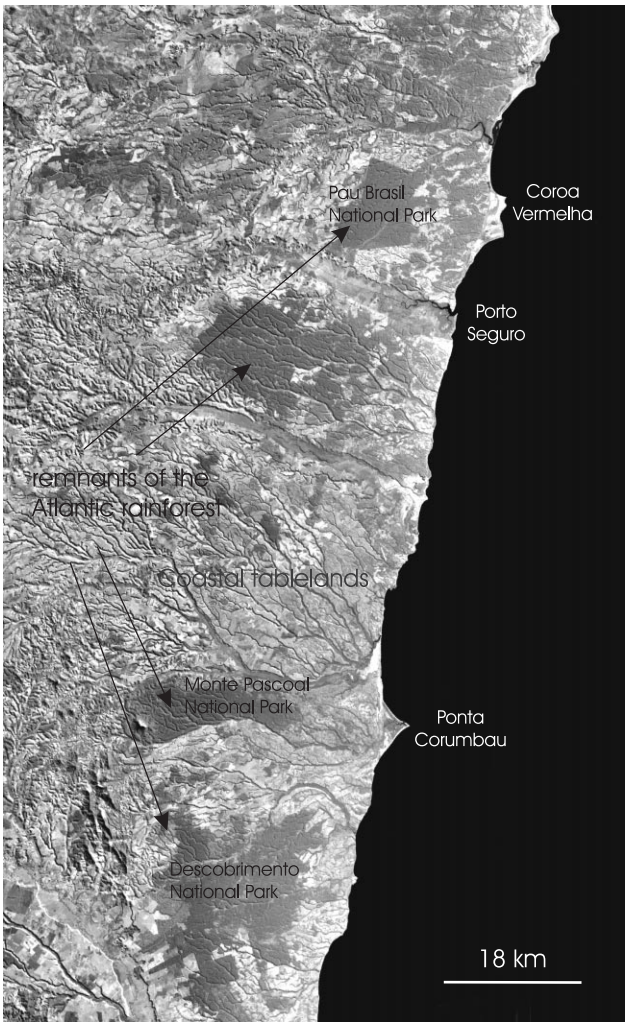

Fig. 5 Satellite image of the southern part of the eastern sector of the tropical coast of Brazil illustrating the coastal tablelands and remnants of the Atlantic Rainforest. Landsat-TM5 image.

Fig. 6 Satellite image illustrating the Paraiba do Sul beach-ridge plain at the southern portion of the tropical coast of Brazil.

(grasses and *Juncus*) dominate. Mangrove forests occur in the lower segments of rivers. The most important mangrove forests in Brazil occur in the Parnaíba river strandplain, in the Todos os Santos and Camamu bays and in the Caravelas strandplain. The dominant species in all these areas is *Rhizophora mangle*.

Major Environmental Concerns and Preservation

Until the 1980s, most of the tropical coast of Brazil was virtually inaccessible. Occupation was concentrated in the major state capitals. The remaining coastal zone was dotted with small villages inhabited by local fishermen and the area experienced economic stagnation. As a result of several plans to develop tourism in the region, massive federal and state government investments were made to build highways which provided easy access to the coastal region. Occupation of the coastal zone has dramatically increased since then, exerting diverse and numerous stresses on the coastal ecosystems. Figure 1 shows locations of major agri-industrial activities, which directly affect the coastal and adjacent marine environments. Heavy industrialization occurs in Fortaleza, Recife and Salvador regions. Major impacts to the marine realm are probably mostly associated with agri-industrial activities (i.e. sugarcane and timber), paper mills, mineral and chemical industries and oil exploration. Most agricultural activity takes place in the tablelands, which, by their morphological nature, offer very favourable conditions for intensive, mechanized farming practices. Carbonate materials (shells and coral fragments) have been mined for many years from Todos os Santos Bay, although this practice has recently been stopped. Studies are presently under way to evaluate the feasibility of exploiting calcareous algae, sand and gravel from the inner and middle shelves. Additional stresses to the marine environment come from increased sedimentation, due to the removal of the Atlantic Rainforest and the disposal of industrial and urban effluents.

Areas where the major reef complexes occur correspond to regions where development is still incipient: nearby urban centres are experiencing accelerated growth and tourist development is increasingly taking a toll on the environment. Today, oil production in Brazil comes, mostly, from offshore basins. The Campos basin, located in the south of this area is, today, the most important producing area. In the rest of the region, major human impacts are related to development of the coastal zone for recreational and tourist uses. These activities have resulted in widespread elimination of the Restinga ecosystem, which in most places has been replaced by developments or by coconut cultivation. This last activity dates back to the eighteenth century.

Institutions concerned with the preservation of the coastal marine ecosystems are fairly new. In the north, a state marine park established in 1991 protects the offshore Manuel Luiz Bank, but it does not prevent the coral bank from being crossed by large ships en route to São Luiz harbour, which exposes the reefs to oil spills and shipwrecks. In the north-eastern sector, an environmental marine protected area was recently designated (1998) that covers a great part of the coast of the states of Pernambuco and Alagoas; this is called the Coral Coast Environmental Protected Area and it is the largest area of shallow coastal reefs so far created in Brazil. Offshore, the Biological Reserve of Atoll das Rocas and the Fernando de Noronha National Marine Park, have made lobster fishing illegal in the atoll and have been controlling marine tourism in the Fernando de Noronha Archipelago. The Fernando de Noronha National Marine Park was created in 1988 and is located about 80 nautical miles eastward of the Rocas atoll.

In the eastern region, one national and two municipal marine protected areas have been created. The oldest is the Abrolhos National Marine Park that protects the richest area of coral reefs in Brazil. The two municipal areas are the Pinaunas Reef Environmental Protected Area at the entrance of the Todos os Santos Bay, designated in 1997 and the Recife de Fora Municipal Marine Park, created in 1998, about 5 nautical miles off the south coast of the state of Bahia. It is a small reef with an area of approximately 11 square miles that has been heavily used for marine tourism. Along the coast of the state of Bahia, reefs not included in park areas are still protected by law, given that the Bahia State Constitution declares that coral reefs are areas for permanent protection. However, enforcement is not yet effective.

Special Government Programs or Non Governmental Institutions protect distinctive faunal elements. For example the TAMAR Project – IBAMA, which protects marine turtles, has several stations along the tropical coast. The 'Baleia Jubarte' Institute, responsible for the study of and concerns about humpback whales, has its headquarters in South Bahia and the Manatee Project, on the coast of the State of Alagoas, has made efforts to protect this endangered animal.

In the coastal zone itself, there are only five national parks. Four are located in the eastern sector. Three (Pau Brasil, Monte Pascoal and Descobrimento National Parks) (Fig. 5) were created with the purpose of protecting remnants of the Atlantic Rainforest. The Restinga de Jurubatiba National Park protects an extensive area of the Restinga ecosystem and the Lençois Maranhenses National Park in the northern sector coincides with a large dune system (see Fig. 2).

Box 1: The Biological Reserve of 'Atol das Rocas'

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Rocas is the only atoll in the south-western Atlantic, and the smallest in the world (Fig. 1). It was the first Marine Biological Reserve created in Brazil, and the only activity allowed is scientific research. It was discovered in 1503 when a sailing boat struck it and sank and from this point onwards, the atoll was regarded as hazardous.

The atoll lies on the western side of a flat-topped sea mount, 260 km east of the city of Natal. Monthly average rainfall is 860 mm and ESE winds dominate, blowing usually at between 6 and 10 m/s. Tides are semi-diurnal with a maximum range of 2.7 m. The atoll lies in the Southern Equatorial Current, which originates on the African coast. Water temperature averages 27°C, though inner pools may reach 39°C. Water visibility during good weather exceeds 20 m.

A reef front, reef flat and lagoon are distinct. On the windward side the reef front is a nearly vertical wall to depths of about 15 m, from which is a flat surface colonized by fleshy and coralline algae, corals and sponges, extending outwards another 1 km. On the lee side a spur-and-groove system develops to depths of 18 m. The reef flat is a ring 100–800 m wide interrupted by pools and two channels, with sandy deposits that are exposed at low tide. Two islets occur on the western side: the Cemitério Islet, which has a cross-bedded beachrock cliff, 1.5 m high, on its north-east side, and the 3 m high Farol Islet which has ruins of a nineteenth century lighthouse. Old reef spits rising 2–3 m above the reef flat surface, called 'rocas' in Portuguese, give the atoll its name.

Soft algae and an association of coralline algae and vermetid gastropods cover the reef surface. The corals *Siderastrea stellata, Montastrea cavernosa, Madracis decactis, Agaricia agaricites, Porites astreoides, Porites branneri, Favia gravida* and *Mussismilia hispida* (Echeverría *et al.*, 1997) occur, mainly in the lagoon, in pools and in grooves of the reef front. *Siderastrea stellata* dominates strongly. The low diversity and cover of corals may have allowed coralline algae to develop more substantially, and an 11 m thick reef framework core, primarily constructed by coralline algae, has accreted at a rapid average rate of 2.8 m/ky (Kikuchi and Leão, 1997).

The Biological Reserve of 'Atol das Rocas' extends to the seamount top at the 1000 m isobath, covering 360 km^2. Created in 1978, conservation activities began in 1990. The first temporary station was established under the auspices of the Marine Turtle Foundation (Fundação Pró-TAMAR) and of the Manatee Project (Projeto Peixe-Boi Marinho – IBAMA). At the end of 1993, a more permanent station was built. It takes about 26 h to reach the atoll from Natal. Research teams, composed of two park rangers (from IBAMA) and six scientists, students or volunteers, rotate every 25 days.

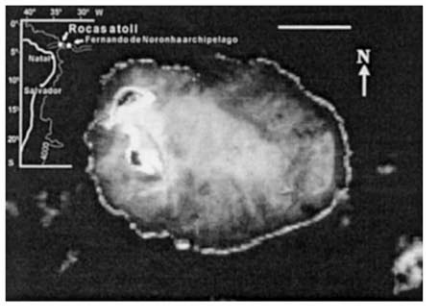

Fig. 1 Satellite image of the 'Atol das Rocas' on the north-eastern sector of the tropical coast of Brazil. Scale bar = 1 km.

Echeverría, C. A., Pires, D. O., Medeiros, M. S. and Castro, C. B. (1997) Cnidarians of the Atol das Rocas. In *Proceedings of the Eighth International Coral Reef Symposium* vol. 1, pp. 443–446.
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Box 2: The Abrolhs National Marine Park

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The National Marine Park of Abrolhos protects part of the largest and the richest coral reefs of Brazil, and of the South Atlantic. It comprises two isolated areas, which include nearshore isolated bank reefs, offshore volcanic islands with fringing reefs, and giant coral pinnacles. The Abrolhos reefs are ecologically unique, and the most characteristic reef growth form, the *chapeirões*, attain their maximum development here, and support communities that thrive in a periodically inhospitable muddy environment.

There are five islands, surrounded by fringing reefs (Fig. 1). The most visited and largest is Santa Barbara (Leão *et al.*, 1994), approximately 1 km long. At its north and south sides are gravelly, sandy beaches, and fringing reefs develop along two-thirds of its shore. Other islands are Redonda Island which has a reef fringe on its southeast, Siriba Island, Sueste Island (500 m long) and the small Guarita Island (100 m across), which is made of volcanic rocks with no sandy beaches. Reef communities grow on its slope. Several are separated by very shallow ($\ll$4 m) water. They are arranged in a ring, though this is not evidence of the remains of an old caldera.

Seventeen stony corals occur, six of which (*Mussismilia braziliensis*, *M. hispida*, *M. hartti*, *Siderastrea stellata*, *Favia gravida* and *Favia leptophylla*) are endemic species in Brazil. Among these, *M. braziliensis* is common but shows the greatest geographical confinement, occurring only along the coast of Bahia. *Siderastrea stellata* and *F. gravida* are similar to Caribbean species and are the most common corals in the shallow intertidal pools. More cosmopolitan corals are minor components in Abrolhos. Two of the three millepores in Abrolhos are Brazilian endemics also: *Millepora braziliensis* and *M. nitida*. The distribution of these and soft corals are quite well known (Castro, 1989, 1990, 1994; Belém *et al.*, 1982).

Fig. 1 Aerial photograph of the Abrolhos Archipelago on the eastern sector of the tropical coast of Brazil, facing to the east. Top left is the Santa Barbara Island, bottom left the Redonda Island, middle of the photo is the Siriba Island and top right the Sueste Island.

An algal flora is abundant on the reefs. The crustose coralline algae *Lithothaminion*, *Lithophyllum*, *Sporolithon* and *Porolithon* are the most abundant genera (Figueiredo, 1997) and are major reef-framework builders. Fleshy algae dominate some reefs around the islands (Amado-Filho *et al.*, 1997), but on further offshore reefs they diminish, possibly due to higher herbivore activity (Coutinho *et al.*, 1993). Most fishes identified in Abrolhos are related to the Caribbean fauna (Nunam, 1979). Thus, the Abrolhos region is the southernmost area of the Atlantic inhabited by a coral reef fish fauna. About 39% of the species are herbivorous (Scaridae, Acanthuridae, Kyphosidae), 54% omnivorous (Haemulidae, Balistidae, Pomacanthidae, Lutjanidae, Pomacentridae) and 7%carnivorous (Serranidae, Carangidae, Sphyraenidae) (Telles, 1998).

Marine turtles visit Abrolhos for feeding and reproduction. In summer, *Caretta caretta* (the loggerhead) and *Chelonia midas* (green turtles) lay eggs on the sandy beaches, while *Eretmochelys imbricata* (hawksbill turtles) feeds on invertebrates from the reefs. The humpback whale *Megaptera novaeangliae* migrates from subantarctic waters to the warmer shallows here. Sea birds, *Sula dactylatra* (blue-faced booby), *Sula leucogaster* (brown booby), *Fregata magnificens* (frigate bird), *Sterna fuscata* (sooty tern), *Anous stolidus* (brown nooddy), and *Phaeton aethereus* (red-billed tropicbird) nest on the islands.

The Abrolhos National Marine Park was created by Presidential Decree in 1983, under the jurisdiction of the Brazilian Institute of Environment and Natural Renewable Resources (IBAMA). It covers about 900 km^2 comprising two areas (see Fig. 1 of main chapter). It includes less than 1/4th of the total area of reefs in Abrolhos. The park was not implemented until 1988, when a Triennial Plan (1989–1991) was prepared based on the experience of the first 15 months of park activity (Gonchorosky *et al.*, 1989). The plan was divided into three main lines of action: environmental protection, environmental education

and support for scientific research. The management plans with conservation programs are already underway (IBAMA/FUNATURA 1991). In the Abrolhos Archipelago, landing is allowed in Redonda and the Siriba islands only under the supervision of a Park technician. In Sueste and Guarita islands, landing, anchorage and diving are forbidden. Santa Barbara belongs to the Brazilian Navy and landing there is only permitted with an official authorization.

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