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Human Disturbance, Natural Resilience and Management Futures: The Coral Reefs of Todos Os Santos Bay, Bahia, Brazil

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Abstract

Between 1962 and 2003 significant coral species changes within reef assemblages at Todos os Santos Bay (TSB), Bahia (Brazil) have taken place, following what appears to have been a 400 year contraction of coral reefs from the inner, landward reaches of the bay. The last 40 years in particular encompassed rapid and extensive urban and industrial development its surrounding lands, which contributed to coral reef changes. However, changes in this environment have influenced coral reef resilience since the arrival of the Portuguese in the XVI century, creating knock-on effects that modified and simplified coral reef ecosystems in the bay. Clues to the limits of coral resilience may be found in natural and human disturbance regimes to which the corals have been subjected in the past, and for that reason we listed and categorized what little is known about Holocene and historical conditions in TSB, proposing alternatives for a resilience management of the bay.

Keywords: Ecological history, Resilience, Phase shift, Coral reefs, Recôncavo, Todos os Santos Bay, Brazil

1. Introduction

One of us (LXCD) took part in work in 2002 logging species changes in coral reefs at Todos os Santos Bay (TSB), Bahia state, Brazil (Dutra, Kikuchi, & Leão, 2006a). In this survey we noted a marked simplification and decline of species since the only previous comprehensive survey in 1962 (Laborel, 1969a). As the large-scale urban and industrial growth of the bay area from ~1950 had likely been a factor in this change, the question arose as to whether the resilience of local systems was sufficiently robust to cope with future man-induced traumas to their environment. We decided to piece together what little evidence there is in the historical and ecological record to ascertain what kind of shocks the coral reefs of TSB might withstand in the future based on what they have survived and evolved from in the near and distant past, in short, the limits of their resilience.

Resilience refers to the potential for continuity and survival in both human and natural systems. An assessment of resilience should try to measure the persistence of relationships within a system and their ability to absorb change of state variables, and still survive with some integrity. The resilience of any given natural system has, of course, evolved from a background of cyclical environmental change punctuated with catastrophes. Even in the relatively stable Holocene, coral reef resilience must have been tested many times at TSB. With the advent of European colonization 500 years ago, human impact on the corals increased through a series of sharp fluctuations following successive land use changes. Whether better management practices in the future can work with nature to improve the reefs' natural resilience is an open question. The best hope to promote sustainability and environmental conservation at TSB in the future is by carefully targeted adaptive management practices (Holling, 1978). The changes that prevailed since Portuguese settlement led to policies and practices that caused further environmental degradation in a positive feedback loop. This paper does not seek to resolve the debate on what could have been done and what caused which impact, but rather, to contribute a management logic that all parties to the debate may find useful. This encompasses adaptive collaborative management (ACM) and should apply to biodiversity conservation both in and beyond formal protected areas (Schelhas, Buck, & Geisler, 2001).

2. Description of the study area

2.1 General Aspects

Todos os Santos Bay is a largely land–locked embayment covering an area of over 1000 km^2 on the east Brazilian coast between 12^o and 13^o latitude south of the equator. The passive continental margin represented by the present Brazilian coast developed into its present general form after the final rifting from Africa at 90 Ma (Cesero, Thomaz-Filho, Mizusaki, & Milani, 2000). Over the last 2 Ma of the Quaternary sea level has fluctuated many times by up to 150 m over the narrow (< 50 km) continental shelf. The region is part of the Recôncavo Basin, formed by Lower Cretaceous fault lines (Medeiros, & Ponte, 1981) associated with continental rifting. The bay itself is delimited by fault scarps, overlain with the sediments of fluvial and tidal deltas (Carvalho, 2000). The surrounds of the bay are composed of Jurassic and Cretaceous sedimentary rocks except for a small area, in the city of Salvador, where the pre-Cambrian basement outcrops along the Salvador Fault. On the northern and western shores, as well as in the various islands inside the bay, Lower Cretaceous shale, siltstone and sandstone (Santo Amaro Group) are the most prominent rocks. The present bay was formed by the flooding of the lower valley of the Paraguaçu River and its tributaries from 8000 years ago by rising post-glacial seas. Only after the rate of rise abated in the early to mid-Holocene could present coral reef ecosystems be established, though the cumulative disturbance history over the entire Holocene would set the resilience regime, and which species would survive or re-establish.

TSB (Figure 1) is the second largest bay on the Brazilian coast with an area, excluding its 91 islands, of 1223 km^2 during high tides and 919 km^2 during low tides and with the inner bay perimeter of 1175 km (Santos, Carvalho, & Lessa, 2003). The Bay has an indented aspect with several attenuated islands providing still more shoreline (Figure 1). Itaparica Island is the largest one, delimiting two channels of water exchange with the open ocean: (i) Itaparica Channel, a shallow-depth passageway in the southwest portion and (ii) Salvador Channel, in the east, deeper than the former with an average depth of 25 m – maximum 102 m. The 10 km wide Salvador Channel provides most of the water exchange between the bay and the ocean (Bittencourt, Ferreira, & di Napoli, 1976; Lessa, Dominguez, Bittencourt, & Brichta, 2001).

Coral reefs presently occur mainly along the ocean-facing southeastern part of Itaparica Island, and on the marine-influenced shores of Frade and Maré Islands (Araujo, 1985; Laborel, 1969a; Leão, & Brichta, 1996) (Figure 1). Reefs are also present elsewhere adjacent to the Salvador Channel, such as Mangueira reef and Periperi reefs on the eastern shores of the bay (Laborel, 1969a) (Figure 1A). The eastern shore of the channel (Figures 1A and B) was also the location of the initial Portuguese settlement and the earliest intense sugarcane production (Diffie, 1987: 71). The Gaituba reefs and those surrounding the Frade channel, between Maré and Frade Islands are, like all surviving reefs, exposed to the E-SE swell through the ocean entrance (Lessa, Bittencourt, Brichta, & Dominguez, 2000). However, a 1764 chart of the bay (Bellin, 1764) clearly shows extensive coral reefs in the inner, estuarine part of the bay, quite far from the marine influence of the Salvador Channel. Local fishermen report that there may still be remnant coral reefs in this northwestern portion of the bay, near Mêdo Island and northwest of Itaparica Island (Dutra, Kikuchi, & Leão, 2006a), but if so they are mere fragments of the 3 km long reefs shown on the XVIII Century map. Leão (1997) (quoted in Lessa, Bittencourt, Brichta, & Dominguez, 2000) believed that present high levels of water turbidity in the inner (western) bay preclude the existence of living coral.

2.2 Environmental Settings

The climate around the Bay is tropical humid, with a ten-year average mean air temperature of 25.3ºC close to Salvador, and a 30 year mean rainfall of about 1900 mm/y (Lessa, Dominguez, Bittencourt, & Brichta, 2001). Three main catchments drain into the TSB conveying an average of 120 m^3/s of freshwater into the Bay. However, since 1985 much of the catchment water yield has been held by the Pedra do Cavalo Dam in the Paraguaçu River (Lessa, Dominguez, Bittencourt, & Brichta, 2001) (Figure 1C), thus reducing the amount and discharge variation of freshwater and sediment reaching the bay (Lessa, Bittencourt, Brichta, & Dominguez, 2000), and thus also probably the general level of water turbidity. The seasonal variation of water discharge from the Paraguaçu River exhibits higher outflows concentrated during summer months (maximum of 3,500 m^3/s) (Lessa, Dominguez, Bittencourt, & Brichta, 2001).

These latitudes are dominated by constant northeasterly and easterly trade winds during the summer and southerly winds in winter (Dominguez, Bittencourt, & Martin, 1992). Hurricanes do not form in the South Atlantic Ocean, and strong seismic disturbance is also rare, so coral resilience in Brazilian waters has not adapted to counter the sharp shocks of these kinds of disturbance (Dominguez, Bittencourt, & Martin, 1992; Leão, 2002). Therefore, local coral reefs are unlikely to have recovery strategies similar to Indo-Pacific and Caribbean assemblages, which are affected by hurricanes/cyclones seasonally and earthquakes intermittently. The relatively low coral diversity of the reefs at TSB, 10 coral species registered in 2003 (Dutra, Kikuchi, & Leão, 2006a), may be a result of this low frequency of acute disturbance (as suggested by the 'intermediate disturbance hypothesis' (Connell, 1978)).

3. A resilience framework to analyze Todos os Santos Bay coral reefs

A resilience framework is needed to assess the impact of historical socio-cultural events compared to natural events on

the TSB coral reef ecosystems. But what is meant by ecological, or for that matter socio-cultural, 'resilience'?

Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb 'change of state' variables, and still persist. Ecological resilience (Holling, 1973; Holling, 1996) 'emphasizes conditions far from any equilibrium steady state, where instabilities can flip a system into another regime of behavior' (Holling, 1996: 33). Ecological resilience assumes that an ecosystem can exist in alternate self-organized or 'stable' states. At each point at which a new organization emerges, the system may branch off into one of a number of possible states. The direction of self-organization will depend on such things as the system's history; it is path dependent and difficult to predict (Berkes, Colding, & Folke, 2003a: 6).

Resilience encompasses the change required to move the ecosystem from being organized around one set of mutually reinforcing structures and processes to another (Peterson, Allen, & Holling, 1998). It is a necessary but usually not a sufficient condition for sustainability (Folke, Colding and Berkes, 2003: 354). In relation to social-ecological systems (SES) - referred to here as the integrated concept of humans-in-nature (Berkes, Colding, & Folke, 2003a: 3) -, resilience is the magnitude of disturbance that can be tolerated before a SES moves to a different state controlled by a different set of processes (Carpenter, Walker, Anderies, & Abel, 2001), as followed the well-known Mayan socio-ecological collapse of the 9th Century.

Unlike sustainability, resilience can be desirable or undesirable. For example, system states that decrease social welfare, such as polluted water supplies or dictatorships, can be highly resilient. In contrast, sustainability is an overarching moral goal that includes assumptions or preferences about which system states are desirable (Carpenter, Walker, Anderies, & Abel, 2001).

3.1 Past Disturbance Regimes at Todos os Santos Bay

Prior to 1500 AD disturbance mostly took the form of cyclical climatic and sea level shifts, which even though comparatively muted during the Holocene were still probably sufficient to force major adjustments of coral ecosystems. There may also have been some small impact from indigenous subsistence practices (fire stick farming, slash and burn agriculture, shellfish harvesting, etc.), but even though these could have been occasionally devastating (for instance, if a severe El Niño drought coincided with a bout of anthropogenic burning) they would have been limited by a small population producing only for local consumption.

Background environmental disturbances must always have influenced coral assemblages. What natural disaster, sea level change or climate cycle might equal or be a proxy for modern human impact? In order to sort out possible past disturbance regimes, Holocene time divisions are outlined below.

3.2 Holocene Disturbance Time Divisions for TSB

3.2.1 20 000 to 8000 years BP

With the present ocean entrance to TSB over 100 m deep, and ocean temperatures at latitude 13^{o} S never likely to have fallen below 20^{o} C even in the last Glacial Maximum 20 000 years ago, the ocean could never have been far from the present site of TSB. However, the rapidity of sea level rise up to the early Holocene precludes any stable coral reef ecosystem either on the rapidly changing outer coast or the shores and shallows of the deepening and expanding bay, until it filled to approximately its present level sometime after 8000 BP (Cruz Jr, et al., 2005; Stute, et al., 1995).

3.2.2 8000 to 5000 years BP

Coral reef initiation and stabilization occurred during the Holocene climatic optimum. Sea level on the Brazilian coast reached a maximum 5 m above present (Martin, Dominguez and Bittencourt, 2003; Martin, Flexor, Villas-Boas, Bittencourt, & Guimarães, 1979). The rate of reef growth was probably higher than the rate of sea level rise, representing a "catch-up" mode of growth (Leão, Kikuchi, Dutra, & Oliveira, 2006; Leão, Kikuchi, & Testa, 2003). However, rapidly rising sea level would allow minimum shore zone for mangrove development or shore stability; with an early period of destabilizing sedimentation as catchment streams and shorelines adjusted to new and changing base levels. This suggests coral assemblages took some time to stabilize, but it also indicates the strong resilience of most coral species in what must have been frequent minor to major adjustments.

3.2.3 5000 to 3000 years BP

El Niño-like events strengthened in the region after 5100 yr BP (Martin, et al., 1993). The El Niño cycle produces large rainfall anomalies and changes in wind patterns, thus affecting sediment transport, salinities and sea surface temperatures, that cause impacts on coral reefs (for more about El-Niño and impacts on coral reefs see Glynn, 1993; Hoegh-Guldberg, 1999; Migotto, 1997). Sea level fluctuated by up to 2.5 m. It dropped from 5m to present sea level at 4 ky BP, quickly rising again from 4 to 3.8 ky BP, lowering again to a 2m about 2 ky BP (Martin, Dominguez, & Bittencourtt, 2003). Reef tops would have endured alternating exposure and inundation, with fluctuating turbidity caused by sedimentation as catchment streams adjusted to new base levels. This again indicates that coral reefs can cope and adapt to considerable natural change and that reef corals were likely to be resilient enough to cope with sea level

changes within TSB.

3.2.4 3000 years BP to 1500 years AD

This period is characterized by a net lowering of sea level, possibly with less fluctuation than the early period (Baker, Haworth and Flood, 2001), but still impacting on vertical growth of the reef surfaces. Reef growth would be inhibited with a slow and relatively steady sea level fall. Over the last 3 ky, the corals have declined significantly in total cover and colony size, as well as undergoing changes in major reef builder species, from the dominance of *Mussismilia braziliensis* to more sediment-tolerant species (Kikuchi, 2000; Kikuchi, & Leão, 1998; Leão, Kikuchi, Maia, & Lago, 1997). However, Carvalho (2000) reported more marine-influenced corals present in the landlocked Paraguaçu Channel around 2300 cal years BP, where all corals are now completely absent. The long-term effects of lowering sea level would be to enlarge shorelines and establish fringing mangroves, if the rivers could deliver the sediment. As the ENSO-like systems were deepening at this time, increased sedimentation was likely (Dominguez, Bittencourt, & Martin, 1992), thus testing the limits of coral reef resilience.

Indigenous folk began slash and burn horticulture in the region during the mid to late Holocene (McNeill, 1986). Extended shorelines and increased bay island areas would both change natural conditions for the reefs and facilitate human use of bay resources, including coastal reefs.

3.2.5 The last 500 years

The limits of ecological resilience have been tested by the events of the last 500 years, following the establishment of an extractive European plantation economy in the region. The process of settlement and development of Brazil since 1500 AD has been characterized by an ongoing destructive exploitation of land and resources (Delson, & Dickenson, 1984). Throughout this period extra-regional forces have driven local ecosystem degradation, namely, Brazil's changing role in the world economy from a peripheral colonial state to a semi-peripheral industrializing economic giant (Wallerstein, 1974). In the colonial period it was the stripping of local resources to send to the metropolitan power that led to environmental degradation: in the modern (post-1950) period it is the addition of imported materials to create exports for the global market that is powering pollution and degradation. Impacts affecting the coral reefs from 1500 AD are related to policies and practices, which took little account of maintaining local ecological sustainability. The next section discusses in detail the human impacts on TSB over the last 500 years.

4. The historical era and its impacts

As a generalization, the extractive economy 1500-1950 would have most affected the inner, enclosed part of the bay, while post-1950 it was the outer bay around the marine channel that was the focus of development disturbance, and consequent fouling of the waters that support the corals. The first detailed description of TSB reefs (Laborel, 1969a) fortunately recorded species composition close to this 'turning point'. That earlier impacts associated with development disturbance back to the XVI and XVII centuries contributed to the bay degradation and subsequent ecological shifts in the coral fauna is strongly suggested by Hartt's (1870) recording of a turbidity-intolerant coral species (*Favia leptophylla*) not noted during surveys inside the bay from 1962 (Laborel, 1969a) or 2003 (Dutra, Kikuchi, & Leão, 2006a), but registered by Araújo (1985) in Itaparica reefs (close to the entrance of the bay Figure 1D). This example strongly suggests that coral reef environments and their resilience have been under pressure since the Portuguese arrived in 1500 AD. The 1870 survey showing contraction in Zone B combined with the 1764 chart, showing now largely absent reefs in Zone C, are likely continuations of a trend from 1500 AD towards a simplified assemblage of turbidity–tolerant species, and away from those waterways most likely to be affected by turbidity, that is, the more land-locked areas of the bay. In this view, Laborel's 1960s description was a moment in a long-term trend of erosion of coral reef resilience. After Laborel's description, there was a 40-year gap (Dutra, Kikuchi, & Leão, 2006a), during which time enormous changes in coral reef ecosystems probably had already occurred due to the shift in land use in the bay's surroundings. Using land use history and its likely enhancement of turbidity as a proxy, coral decline may reasonably be separated into four historical periods: (i) pre 1500; (ii) from 1500 to 1850; (iii) from 1850 to 1950 and; (iv) after 1950 (Table 1).

4.1 Historical Disturbances: From 1500 to 1850

When the Portuguese first arrived in 1500, the Recôncavo was heavily forested (Schwartz, 1985: 77) with only a few indigenous groups practicing agriculture (McNeill, 1986). The introduction of commercial agriculture (Miller, 1997: 147) affected soil through the enlargement of land clearing areas, especially for the establishment of sugarcane plantations, and involved large scale forest clearing for sugarcane and sugar-mill fuel in zones A, B, and C (Miller, 1997: 137). Livestock, cotton and tobacco production followed, and shipbuilding for Portugal's worldwide navy exacted a further toll on forest resources (Diffie, 1987: 176; McNeill, 1986; Miller, 2003; Morton, 1978; Silva, 1987). In a high rainfall area of steep relief erosion was inevitable, and the waters of TSB carried the sediment burden with its potential to impact the reefs through enhanced turbidity.

Evidence from other parts of the European colonial frontier (Gale, & Haworth, 2005; Haworth, Gale, Short, & Heinjes,

1999) shows that initial clearance and disturbance of new lands usually results in a massive leap in erosion and sedimentation until the easily available sources of sediment are depleted, and a new ecosystem state is established. This condition will last until disturbed by the next wave of development, with early opening of lands for commercial agriculture and later infrastructure development often tapping into different sources of sediment. Thus one would expect a pattern of high magnitude sediment dumps followed by lower and steady state sedimentation over the last 500 years, with the boom and decline of certain agricultural products and resources (see Table 1) reflected in different high sedimentation events. These are the land-based events that are most likely to have affected coral reefs.

A 1764 map (Bellin, 1764) indicates coral reef areas in the northwest coast of Itaparica Island (Figure 1D) where they are not present today. Interestingly, this coincides with the date when fierce resistance by the native Americans was finally overcome and the southern area of the Bay (zone D) was opened to land clearing and commercial plantation production already established in the north and east areas (C, B, and A) from the XVI century (Schwartz, 1985: 32). The shock of initial commercial development was apparently of sufficient magnitude to overcome the resilience of inner estuary reefs. The XVIII Century event was indirectly recorded by the mapping of what had been, and we know is now all but gone. It is reasonable to assume that an earlier contraction of coral coverage and assemblage had occurred in the northern part of the bay. As well as geographical shifts in cultivation around the Bay over five centuries, each change in demand and fashion of the world market led to a boom or decline of a given product, with knock-on effects to resource extraction and depletion that through erosion and sedimentation would eventually manifest themselves in reef degradation and change. The natural resources of the bay, exemplified in healthy ecosystems such as coral reefs, allowed the local peoples to survive these boom-bust cycles. However, the erratic and predatory nature of the plantation economy appears to have been gradually undermining the resilience of these resources: benefits were mostly transferred overseas, while land and water degradation problems were left for the locals to negotiate.

4.2 Historical Disturbances: From 1850 to 1950

The economic development of Bahia state had stagnated by 1872 (Furtado, 1963: 104), with the rate of growth dropping to zero, with abandoned land haphazardly exploited in a new pattern by subsistence farmers, who also depended heavily on marine resources. Hartt (1870) provides an example of changes in coral communities for this period. He describes the presence of a coral species (*Favia leptophylla*) in the fringing reefs of Itaparica Island not present in the later surveys (Dutra, Kikuchi, & Leão, 2006a; Laborel, 1969a).

Hartt (1870) also registered mining on the coral reefs of the seaward side of Itaparica Island, with coral burned to produce lime. However, coral mining had started at least by the second half of the XVI century, when Soares de Souza (quoted in Miller, 1997: 152) mentioned “three lime producers on the Island of Itaparica where quarried chunks of limestone [probably from Itaparica reefs] were placed in vaulted kilns and pulverized by the heat from large wood fires burning day and night”. Laborel (1969a) suggested that such exploitation had contributed to the degradation of Itaparica reefs.

Salvador’s economic development stagnated during the first four decades of the twentieth century, though the city remained a commercial entrepôt for the region. New economic activity with far reaching effects on Bay ecology started in 1939, when oil was found within the city limits of Salvador in the surrounds of Tainheiros cove. By 1941, four Bahian wells were producing 230 barrels a day (Herold, 2004). Major disturbances and impacts on coral reefs are indicated in Table 1.

4.3 Historical Disturbances: From 1950 to the Present

Economic growth within the Recôncavo region driven by oil production greatly increased industrial and domestic runoff into the bay. A cement plant constructed in 1954 in Zone A increased muddy sediment supply to TSB. Marine carbonate deposits within TSB were exploited and processed in this cement plant. The muddy residue waste dumped in the bay increased water turbidity (Dutra, Kikuchi, & Leão, 2006a).

The 1960s were the most intense industrialization period in the Recôncavo. The landscape changed from predominantly agricultural to industrial in Zone A (Herold, 2004). Around 200 industries were established in the region, including metallurgic, textile, and chemical plants (Wasserman, & Queiroz, 2004). Paredes et al. (1995) argue that environmental quality at TSB was aggravated during the decade between 1982-1992, particularly on the estuarine waters of Subaé River on Zone B, where all concentrations of heavy metals sharply increased in sediment. Heavy metal concentrations in some areas of TSB exceeded permissible concentrations. A successful industrial economy meant contamination of the TSB waters.

Population growth (Table 2), associated with industrial development, added to the degradation of the bay (Wasserman, & Queiroz, 2004). More sediment and sewage were discharged into runoff entering the bay waters. There was also an increase in fishing pressure, including the use of illegal practices, such as dynamite fishing (Dutra, Kikuchi, & Leão, 2006a). Uncontrolled ornamental fish collection helped to decrease reef stocks and reef habitats (Rosa, Sampaio, & Barros, 2006). Increased ship traffic resulted in ships running aground on the coral reefs (the last one recorded in TSB

in 1998). In addition, alien species were accidentally introduced into TSB waters competing with native species with the potential to impact marine biodiversity (Sampaio, & Rosa, 2006).

The growth of Salvador city, in 2000 with around 2.4 million inhabitants (Table 2) (IBGE, 2006), required the construction of the Pedra do Cavalo Dam in 1985, 20 km upstream from the estuary on the Paraguaçu River (Paredes, et al., 1995) (Zone C), which debouches on the west side of TSB. This marked a change of continuous low-level of stormwater inwash and sedimentation by random urban development disturbance, as opposed to the previous regime of high-magnitude freshwater floods and sedimentation in the wet season to high-saline low-sedimentation in the drier season. This interacted with the industrial changes of the previous decades to create a qualitatively new marine turbidity environment that the corals have to cope with, and almost certainly presage marked changes in the coral fauna and assemblages in the immediate future.

We argue that changes in TSB waters, as a result of land clearing, which increased sediment levels of runoff (from 1500 to 1950) likely affected coral communities through ecological shifts. The period from 1950 to 2006 is characterized by stronger urban population growth and industrial development. This expressed itself as greatly increased nearfield disturbance of the coral reef areas with a countervailing decrease of farfield sources of sedimentation by river damming. A countervailing force is explicit state policies aimed at improving water quality in the Bay, but which have not yet had time to take effect.

5. Discussion of resilience prospects of TSB reefs

The new conformation assumed by coral reefs after a disturbance will depend on several factors, including: (i) connectivity through larvae supply from non-impacted reefs (Roberts, 1997); (ii) ecological relationships (predation, competition) within the reef; and (iii) water quality. These are influenced by the development and growth occurring in Recôncavo lands. Regional industrial growth has come at the expense of environmental damage through habitat destruction impacting traditional communities that depend on extraction of natural resources from the Bay. If this pressure exceeds certain environmental limits it risks irreversible decline of regional ecosystems (van den Bergh, 1995), damaging social-ecological resilience.

Typically, components of resilience are allowed to decline or are deliberately eliminated because their importance is not appreciated until a crisis occurs. Human-sourced degradation of coral reefs increases vulnerability to natural impacts, such as storms. Instead of absorbing recurrent disturbances as they have done for millennia, many overfished and polluted reefs undergo radical regime shifts. Coral populations may fail to rebuild after external shocks and instead are replaced by other ecological states (Adger, Hughes, Folke, Carpenter, & Rockström, 2005). These authors suggest that re-building resilience - by improving water quality and maintaining adequate stocks of herbivores (fish, sea urchins) - can promote the regenerative capacity of corals to recurrent disturbances. The intensity and pattern of human-induced disturbances on the ecological states of TSB coral reefs present an unprecedented test of their resilience.

5.1 Coral Reef Resilience After 1950

Dutra, Kikuchi, & Leão (2006a) indicated that in most reefs surveyed at TSB in 2003, filamentous algae dominated reef tops. Filamentous algal turfs are typically the first macroscopic colonists of reef substrata after storms, bleaching events and anthropogenic perturbations (Witman, 1992).

However, the persistence of corals or algae is dependent on external factors that may favor the development of a coral-dominant or algae-dominant state. Vulnerability (the opposite of resilience) can be high, as a consequence of human-induced impacts, such as herbivorous overfishing, and/or by die-offs of other herbivorous groups (Hughes, 1994) and runoff pollutants affecting the corals (Table 1).

Although the Brazilian coral fauna developed in the context of turbid waters (Laborel, 1969a, 1969b; Leão, 1982), there is strong evidence indicating that threshold levels of blanketing turbidity have been reached for reef corals, with consequent decline of coral reef resilience. The difference between the 1962 and 2003 surveys is mainly in the disappearance of coral species that are least resistant to water turbidity and sedimentation (Dutra, Kikuchi, & Leão, 2006a) (Table 3).

Disturbance changes that have occurred in the landscape since Portuguese settlement and until 1950 in the Recôncavo were all along the lines of increasing sedimentation and turbidity, but in a more piecemeal fashion than post-1950, so that damage to one area could be repaired by larvae from elsewhere in the Bay. The changes since 1950 have been those of both degree, and following the damming of the river and industrialization of the eastern shore, changes of kind.

5.2 Geological Evolution of TSB Reefs Analyzed Through a Resilience Perspective

During the last 8000 years of geological evolution of coral reefs at TSB, three different coral reef states – in relation to dominance and size of coral colonies – can be identified (Table 4). Data from Dutra, Kikuchi, & Leão (2006a), Kikuchi, & Leão (1998), Leão, & Kikuchi (1999), Leão, Kikuchi, Dutra, & Oliveira (2006) and Leão, Kikuchi, Maia, & Lago (1997) were used in this analysis.

In the first phase of reef development, throughout the first transgressive phase of the sea level (from 8 to 5 ky BP), large and widespread colonies of *Mussismilia braziliensis* were the main reef builders. This situation is found in present coral reefs located 70 km off the south coast of Bahia in Abrolhos reefs (Kikuchi, et al., 2003). A second (regressive) phase (after 5ky BP) is characterized by increase in turbidity and sedimentation – and its damage to reef corals (for more on deleterious impacts of sedimentation and turbidity in reef corals see Abdel-Salam, & Porter, 1988; Dutra, Kikuchi, & Leão, 2006b; Rogers, 1990; Te, 1992; Woolfe, & Larcombe, 1999), associated with a falling sea level and consequently a probable reworking of newly exposed littoral sediments, which approached coral reefs to shorelines favoring an ecological state constituted by small colonies of *M. braziliensis* and changes in the dominant reef coral species. A third phase occurred sometime between 1962 and 2003, characterized by the absence of *M. braziliensis* within the bay and changes in species composition, which favored the species most adaptable to high sedimentation and turbidity (Table 4).

Changes in coral communities from 1500 AD were an indirect result of an extractive economy stripping the land and speeding sediment transport to the bay: changes after 1950 were a result of pollution inputs often from far away to a new industrializing economy, and in the case of the dam a starving of previous sediment and fresh water transport.

6. Current Management Practices at Todos os Santos Bay

Much of natural resource management has been an effort to control nature in order to harvest its products, reduce its threats, and establish highly predictable outcomes for the short-term benefit of humanity (Holling, & Meffe, 1996). For Berkes, Colding, & Folke (2003a: 15) a resilient social-ecological system is synonymous with ecological, economic, and social sustainability: human aspirations are thwarted if the commons of land, air and water are debased and depleted. Any system with low resilience has limited sustainability; it may not survive for long without flipping into another state.

This approach to solving problems may be collectively referred to as "command-and-control" (Holling, & Meffe, 1996). The command-and-control approach implicitly assumes that the problem is well bounded, clearly defined, relatively simple, and generally linear with respect to cause and effect. But when these same methods of control are applied to a complex, nonlinear, and poorly understood natural world (such as the coral reefs and catchments of TSB), and when the same predictable outcomes are expected but rarely obtained, severe ecological, social, and economic repercussions may result. These repercussions have occurred since the arrival of the colonial economy.

The combined impact of 500 years of exploitative development saw the decline of local coral reefs. By the middle of the XX Century, after the long decline of the colonial plantation economy, an increased national emphasis on industrialization resulted in widespread industrial activity, increased shipping, and urban expansion along the eastern shoreline of the bay. This was also where earlier Portuguese plantation production had been most intense and, coincidentally, the most important coral reef area. After about 1950, industrial pollution, urban contaminants (e.g., untreated sewage), ship traffic, overfishing (with the use of wasteful and destructive fishing practices), in association with the already high levels of sedimentation of TSB waters contributed to a shift in coral species composition of TSB reefs (see Figure 1; Table 3). In the last 25 years government policies have recognized the damage done and attempts have been made at legislative control and planning for sustainability (see Federal Act 6902 from 27/04/1981(Editora Saraiva, 2006)). Well meaning laws and regulations, however, are often frustrated by sectional interests who can export the costs of their operations to others in the form of environmental degradation, and an insufficient public understanding that individual well-being is dependent on clean air and water as well as narrow economic development.

There are three main issues concerning the conflict between urban development in the Recôncavo and the environmental impacts affecting the reefs (van den Bergh, 1995): (i) by exporting pollution, or importing natural resource materials, regions may develop quickly but at the cost of extra-regional environments; (ii) extra-regional support of development and growth may push a local economy beyond certain regional environmental limits, at the risk of irreversible destruction of the area's ecosystems; and (iii) the risk may become more serious when factors outside the region strongly push internal growth

7. The role of adaptive management at Todos os Santos Bay

ACM contrasts sharply to current natural resource and environmental management applied at TSB, where nature was (and maybe still is) seen as a trove of latent commodities awaiting harvest. From what was described in section 4, environmental stability and resource permanence were vaunted management goals. Uncertainty, disorder, and unpredictability - elements naturally and inevitably present throughout the Holocene - were anathemas. During the historical era, policy-makers and managers had little appreciation of chaos or the dynamic uncertainties of nature. Ecosystem services were segmented and defined in anthropocentric terms (Schelhas, Buck, & Geisler, 2001: xx).

Adaptive collaborative management is an approach to understanding, justifying, and implementing policies that affect the environment (Norton, 2005: 92). It is a management strategy where the ideas of both natural resource managers and local communities are put together and used in experimental fashion. It includes community learning and intentionality in participation based on knowledge (academic, practical, traditional) and explicit assumptions. With this method all

approaches are valid for natural resources managers if they contain the following three key tenets (Norton, 2005: 92):

1). Experimentalism. Adaptive management emphasizes experimentalism, taking action capable of reducing uncertainty in the future: The method used by adaptive managers is a commitment to using experience to reduce uncertainty and to adjust goals and commitments. Experimentalism implies that nothing should be taken for granted and that wherever possible assumptions should be replaced with beliefs based on experimentation and careful observation. Goals and objectives set for policy, as well as physical models, should be open to amendment. The very goal of sustainable living is a moving, changing target, to be defined as part of a process as more experience pours in.

2). Multi-scalar analysis. Adaptive managers understand, model, and monitor natural systems on multiple scales of space and time: One important aspect of this second characteristic is a commitment to open systems, to understanding nature and the environment as a complex and multi-scalar interaction of parts. Since the parts change at different rates, multi-scalar understanding introduces the possibility of emergent qualities, qualities of larger wholes that cannot be understood as the sum of actions of parts. This second characteristic allows us to interpret impacts that emerge on different scales in terms of a single, integrated model and allows the integration of models over multiple levels.

3). Place sensitivity. Adaptive managers adopt local places, understood as humanly occupied geographic places, as the perspective which multi-scalar management orients. The third characteristic of adaptive management is localism, a commitment to examine each problem in its particular context and to pay attention to differences that matter in a "place". Environmental management as community adaptation to a "place" is thus locally based. This is not to say, of course, that regional and global systems never impact local systems - but rather to say that the survival of the community takes place against the back-drop of changing systems on many scales, as these are viewed from the perspective of the local community. These complex, interlocking dynamics must be understood from a specific, local place, from a given perspective within a multi-scalar system.

Based on these tenets, ACM is seen as a strategy that: (a) proceeds in a learning process mode rather than according to a universal *a priori* blue print; (b) considers errors, mistakes, and failures not in normative terms but as normal occurrences resulting from policy experiments; (c) engages both local and non-local stakeholders in a participatory process of goal setting, planning, management experimentation, and evaluation; and (d) utilizes a variety of methods to generate knowledge that keeps pace with ecosystem change resulting naturally or from expanding human activity (Schelhas, Buck, & Geisler, 2001: xix).

Building coral reef resilience at TSB requires the maintenance of crucial ecosystem elements outside the marine habitat, such as the soil. It is unlikely that resilience will be achieved through traditional approaches, such as command-and-control. The complex relationships between humans and nature require adaptive management practices that are inclusive and flexible, able to deal with uncertainty and surprise (Berkes, Colding, & Folke, 2003a). ACM seems to be the most suitable strategy to foster coral reef resilience at TSB because it seeks to accommodate the power of both science and lay knowledge for building management models, testing them, learning from them, and - ultimately - applying them to conservation and sustainable development (Schelhas, Buck, & Geisler, 2001: xx).

8. What resilience represents for sustainable coral reef management at Todos os Santos Bay?

Given that change to coral reef systems at Todos os Santos Bay has accelerated in both degree and kind, what may be options for managing social-ecological resilience?

Coral reefs are highly productive hotspots of biodiversity that in TSB have supported traditional low-key fishing and gathering. Their protection, therefore, is a socio-economic, as well as an environmental imperative (Hughes, et al., 2003). Managing coral reef resilience at TSB requires a complex view that the 'normal' state of nature is not one of balance and repose but the one to be recovering from the last impact (Urry, 2005). If the ecosystem is resilient enough, changes will occur but ecological services will still be provided.

Coral reefs have complex marine environments where relevant scales in time and space are many and varied (see Hughes, 1994; Hughes, Ayre, & Connell, 1992; Hughes, et al., 2003; Hughes, Bellwood, Folke, Steneck, & Wilson, 2005; McManus, & Polsenberg, 2004; Wood, 1998; Wood, 2001). Coral reef management must account for their wise use, and the social and cultural values of local and traditional people (Fernandes, Ridgley, & van't Hof, 1999).

The reestablishment of an individual coral reef will depend on a matrix of reefs in the surrounding seascape and in their resilience (Nyström, & Folke, 2001), as well as on the resilience of related ecosystems, such as riparian forests, wetlands and mangroves. It means that reefs and other ecological areas must be connected through a network of protected areas (PA) (Bellwood, Hughes, & Nyström, 2004; Hughes, et al., 2003; Hughes, Bellwood, Folke, Steneck, & Wilson, 2005). TSB is part of the Bahian PA network subjected to State regulations (Bahia State Act 7595 in Constituição do Estado da Bahia, 2005). The coast of Bahia includes a network of PAs covering coral reefs, mangroves, and rainforests from north to south with limited functionality, however. In addition there is the Abrolhos Marine National Park, a federal PA in the south of the state, created by the Federal Act 88218 from 6/4/1983 (Editora Saraiva, 2006). Legislation must be enforced and PAs have to be strongly linked because connectivity promotes resilience

(2003). Coral reefs have large extensions, they are dependent on decisions taken elsewhere and thus their conservation and sustainable use requires an effective landscape-seascape perspective.

In relation to dynamite fishing, along the coast of the state of Bahia all reefs are protected by the Bahia State Act 215 Chapter VIII (Constituição do Estado da Bahia, 2005) as areas of permanent protection. However, Leão, Kikuchi, & Testa (2003) argue that legislation enforcement is not yet effective, which still allows widespread use of destructive techniques at TSB coral reefs. The aim is to make legislation effective by creating the moral climate where such practices are abhorrent to the general consensus.

The creation of PAs without incorporating local communities' needs and visions reinforce the thesis that legislative attempts will not be effective unless their ethical underpinning is accepted by the affected human communities. If PAs are to be created within TSB and other parts of the Bahia state, they should encompass alternatives (ecotourism jobs, sustainable resource exploration) with local communities. PAs to be effective should provide not only ecological benefits, but social and economic as well.

Berkes, Colding, & Folke (2003a: 15) emphasize that in operationalizing resilience, managing for sustainability in socio-economic system means not pushing the system to its limits but maintaining diversity and variability, leaving some slack and flexibility. For Berkes, Colding, & Folke it also means learning how to enhance adaptability, and understanding when and where it is possible to intervene in management. 'Soft' management approaches are preferable to 'hard' management involving quantitative targets. 'Hard' management tends to be incomplete or even misleading in the management of the ecosystems of the world.

Alternatives to manage reef resilience preclude command-and-control approaches (Hughes, Bellwood, Folke, Steneck, & Wilson, 2005). Instead, reef resilience management requires an ability to detect and react to social-ecological-economic feedbacks (Berkes, Colding, & Folke, 2003b). Hughes, Bellwood, Folke, Steneck, & Wilson (2005) state that currently, feedbacks from damaged ecosystems are often masked by selling off natural capital to maintain short-term incomes (i.e. by mining resources until they become economically unviable), a common approach since the XVI Century at TSB. These economic substitutions through serial depletion of resources temporally or spatially also masked reef ecological decline. It is more than likely that the first deteriorations in coral reefs (reduced coral cover and fisheries, for instance) were masked by the economic growth associated to logging, sugar and other crops. Schwartz (1985: 82) reports some areas within TSB were already over-fished by the second half of the XVI Century.

Hughes, Bellwood, Folke, Steneck, & Wilson (2005) proposed that successful approaches to SES management require four attributes: embracing uncertainty and change, building knowledge and understanding of resource and ecosystem dynamics, developing management practices that measure, interpret and respond to ecological feedback and supporting flexible institutions and social networks in multi-level governance systems.

An alternative to cope with unpredictability is to actively engage stakeholders through bottom-up strategies. Meppem, & Gill's (1998) alternative is to develop a process to better understand the socio-cultural context of the environmental and economic information and judgment underlying development scenarios. In this approach, the task of planners and managers is to catalyze bottom-up solutions. Policy makers should facilitate learning and seek leverage points with which to direct progress towards integrated economic, ecological and socio-cultural approaches for all human activity.

An important issue is public awareness about the state of TSB. In order to engage interested parties in active management participation, inhabitants of the Recôncavo area and Salvador must be made aware of depletion or improvements of the social, ecological and economic states around the Bay. Identity and sense of place are complex concepts, considered to be linked to practical activities of people, people's perceptions of an ecosystem, and the relational networks that people build within an ecosystem (Davidson-Hunt, & Berkes, 2003: 73).

An example of an approach within the ACM framework is provided by Dutra (2007). He described a detailed methodology to deal with the management of coral reef resilience in a fishing village in East-Timor. His methodology included methods from 'Organizational Learning' (OL), a term borrowed from the business literature, which involves the detection and correction of errors in business organizations (Argyris, & Schön 1978: 2-3). Systems Thinking provides the context to use OL methods, such as Systems Dynamics (SD) modeling and conversation-based collaborative processes, which emphasizes that the activity of conversation itself is the key process through which forms of organizing are dynamically sustained and changed (Shaw, 2002: 10). The use of SD was useful for testing policies in models that integrated ecological, socio-cultural and economic concerns.

Overall, a public awareness campaign and an argument for jobs in tourism and environmental protection are good alternatives. However it must be a diffuse solution and should encompass the collaboration of a diverse set of actors operating at different socio-economic and ecological scales. The chronic disturbance factors are diffuse, so it must be a 'whole of catchment', 'whole of Bay' and 'whole of society' solution - a sense of local ownership and stewardship for the locals, and 'wise use' conservation ethic everywhere and informing government policies. One hopeful sign,

paradoxically, may be the large and increasingly diverse population. While raw population growth has caused many of the problems, nonetheless the evolving community is not just a small group of resource exploiters far from the public eye, but also the increasingly sophisticated and aware citizens of a rapidly industrializing nation. The last few decades have seen the great cities of the world cleaned up from rabid and extreme pollution (whales sighted in the River Thames) - as Brazil takes its place as a leading nation of the world, there is no reason why national pride cannot be channeled to effect an environmental improvement, just as it has elsewhere in the developed world.

9. Conclusions

The process of settlement and development in Salvador and the Recôncavo since 1500 AD has been characterized by destructive exploitation of land and natural resources. Such deleterious practices have operated over the five centuries since the arrival of the Portuguese. The 'cultural landscapes', which have evolved over that time with the growth of farms, sugar mills, towns, and industries are not merely the products of such negative processes, but are at least in part the consequences of deliberate strategies by central authorities seeking to shape the path of development (Delson, & Dickenson, 1984).

As in other parts of the world industry has treated the environment at TSB as provider of resources and a recipient for residues from production and consumption. This attitude has caused widespread environmental destruction and contamination of air, water and soil (Gutberlet, 2005), impacting communities and the environment at the same time.

The consequences of different phases of development have impacted the coral reefs since 1500. It is more than likely that reefs at TSB changed their ecological composition several times between 6000 BP (the Holocene highstand) and 1500 AD as a result of climatic and/or sea level cycles, and maybe shifted as many times in the last 500 years from anthropogenic impacts. The changes of the last 50 years, and what threatens in the next few decades, could well lead to a radical loss of ecological resilience, causing impacts in the social ecological system, i.e. when the state of the ecosystem is so altered that can be irreversible (Holling, Schindler, Walker, & Roughgarden, 1995; Moberg, & Folke, 1999).

There is little likelihood that reef recovery to pre-1500 states will take place. However, changes in coral reef ecological conditions will be achieved only if water quality is improved within the Recôncavo area and its catchments, which would also be of immense benefit to the burgeoning human population of the state and their legitimate aspirations for a clean environment. This will be possible only with the inclusion of socio-cultural, economic and ecological interests in one framework, for management, governance and policy-making purposes. Adaptive collaborative management provides the best framework to incorporate these interests.

The loss of social-ecological resilience is affecting the capacity for renewal of coral reefs and thereby the quality and quantity of their delivery of ecological goods and services. Coral reefs in the context of the Brazilian economy are passive receivers of decisions taken elsewhere. Their ecological resilience faces an unprecedented challenge from human disturbance in Todos os Santos Bay: only human intervention and management based on a whole landscape-seascape perspective (Moberg, & Folke, 1999) can ensure their survival by policies where sustainable ecological and socio-economic health is promoted together.

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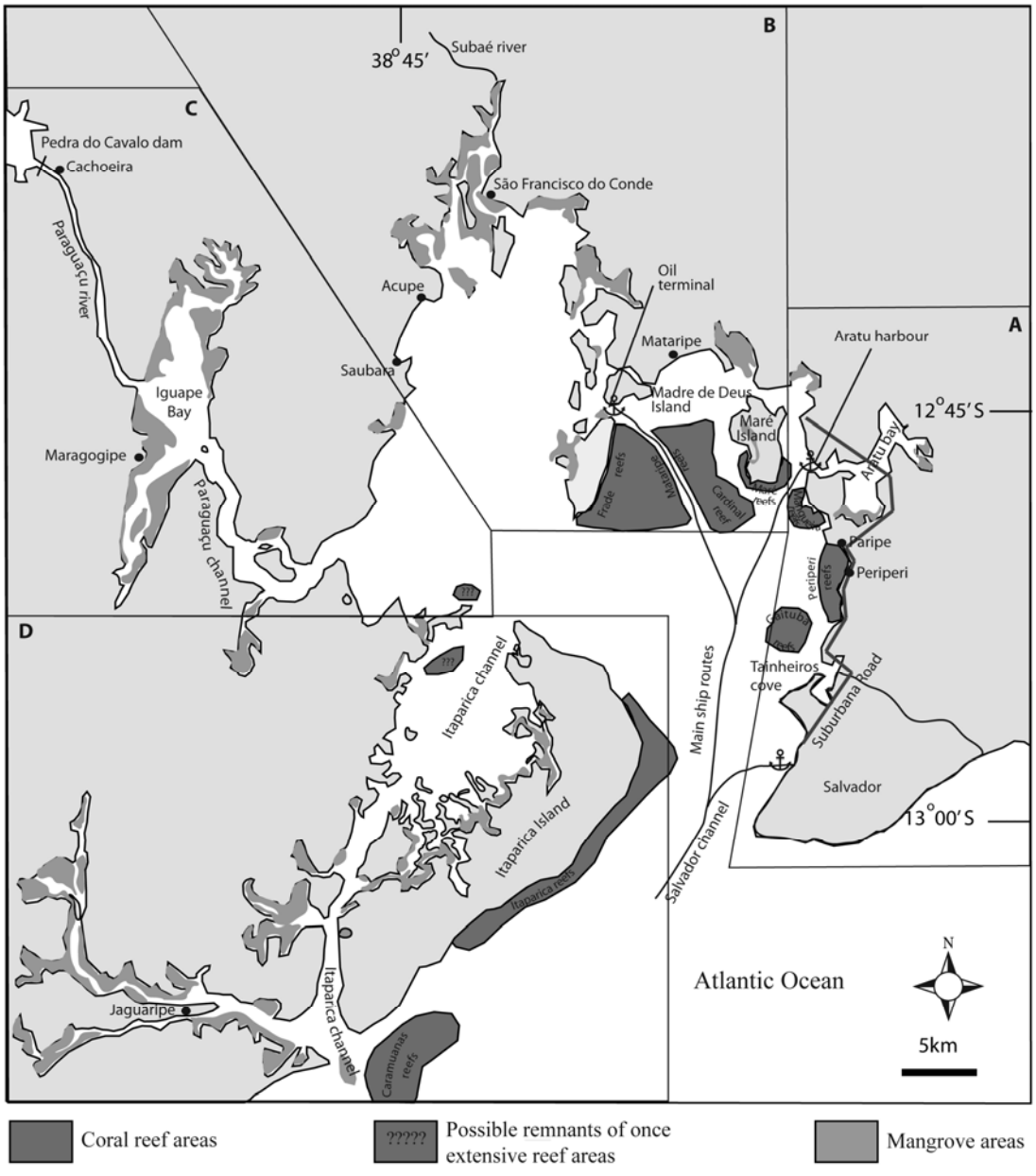

Figure 1. Map of Todos os Santos Bay including coral reef and mangrove areas

(based on Lessa, et al., 2000) and source areas of impacts

A) Initial Portuguese settlement producing sugarcane, cotton and other plantation crops in the XVI Century; Area subjected to intense industrialization in 1960s and 1970s;

B) Establishment of sugar plantations in the late XVI Century which became the second largest sugar production area; Mataripe oil refinery built in 1950s and; establishment of two industrial zones contributing to industrial and domestic runoff into the Bay's waters;

C) Establishment of sugarcane plantations in the late XVI Century; area devoted to livestock grazing and manioc cultivation around the towns of Acupe and Saubara; Tobacco production area;

D) Only opened to settlement in the XVIII Century, with manioc farming during the colonial period; timber and firewood reserve for whole region; lime mining on ocean-facing Itaparica reefs in the 1860s.

Table 1. Major impacts to coral fauna at Todos os Santos Bay since 1500

Period	Major impacts	Effects on the coral fauna
Pre 1500	Sea level oscillations. Storms generating periodic increase in sedimentation and turbidity. Floods maintain fresh/saline variations, and probable annual sedimentation peak. Slash and burn agriculture, shell gathering and reef fishing by Indian tribes.	Sea level oscillation caused changes in dominance of coral species over the reefs and reduction of coral colonies. These impacts were recorded on a time-scale of thousand of years (see section 3.2), but some fluctuations may have been rapid and up to 5 m. Anthropogenic impacts may have caused low-level damage to coral reefs.
1500 - 1850	Intense land clearing. Substitution of traditional low-scale agriculture to the European plantation large-scale methods. Change from an economy based on use (Indians) to one based on profit and export (European). Establishments of towns, urban population, shipping. Mining on coral reefs for lime for construction.	Increase in soil erosion and rates of sediment runoff causing impacts on reef corals in a time scale of tens to hundreds of years. Mining and shipping cause physical damage to reef framework.
1850 - 1950	Economic stagnation and the decline of sugar. Abandonment of agricultural land, increase of indiscriminate grazing. Establishment of heavy industry. Intensification of population growth.	Abandoned lands too degraded for regrowth, constant opportunistic grazing accelerates soil erosion and sediment runoff. Introduction of new pollutants through industrial development.
1950 - Present	Oil exploration and refining. Strong industrial development. Massively expanded urban development and service expectation (sewage, etc.). Widespread industrial and domestic pollution of TSB waters through air and runoff (including heavy metal contamination). Increase in fishing pressure and the use of dynamite fishing. Increase in container ship/tanker traffic, needing dredging and expanded marine infrastructure.	Chronic impacts affecting the reefs 24 hours a day, seven days a week. Widespread destruction of reef framework. Ships/tankers stir up sediment re-suspension on sea floor close to reef areas, plus shipwrecks and oil spills. Heavy metals impact coral larvae and adults.

Table 2. Population of the city of Salvador from 1585 to 2000

Year	Salvador Population
1585	14 000 (Schwartz, 1987: 129)
1620	21 000 (Herold, 2004)
1724	25 000 (Schwartz, 1987: 129)
1750	40 000 (Schwartz, 1987: 129)
1950	417 235 (Herold, 2004)
2000	2 443 107 inhabitants (IBGE, 2006)

Table 3. Presence of coral species in 1962 (Laborel, 1969a) and in 2003 (Dutra, Kikuchi and Leão, 2006a)

Coral species	1962	2003	Observations
Madracis decactis	Not reported	Uncommon	Adapted to unfavorable conditions in water quality (Guzmán, & Guevara, 1998)
Agaricia agaricites	Not reported	Uncommon	
Siderastrea stellata	Main reef top builder	Main reef top builder	Resistant to high turbidity (Laborel, 1969b); the genus *Siderastrea* is adapted to low luminosity environments (Guzmán, & Guevara, 1998)
Porites astreoides	Not reported	Uncommon	Resists turbid environments well. (Laborel, 1969b) and is very resistant to sedimentation (Torres, & Morelock, 2002)
Porites branneri	Abundant	Not reported	Low resistance to water turbidity (Hetzel, & Castro, 1994; Laborel, 1969b; Veron, 2000)
Favia gravida	Abundant	Uncommon	Is highly tolerant to environmental oscillations in temperature, salinity and turbidity (Laborel, 1969b).
Montastrea cavernosa	Main reef top builder	Main reef top builder	A sediment-tolerant species (Bak, & Elgerhuizen, 1976; Torres, Chiappone, Geraldes, Rodriguez, & Vega, 2001); present in turbid conditions (Laborel, 1969b), and is adapted to low light level environments (Guzmán, & Guevara, 1998).
Mussismilia harttii	Abundant	Uncommon	Tolerates well a certain amount of turbidity (Laborel, 1969b) and is associated with shallow, turbid reef environments (Veron, 2000).
Mussismilia hispida	Abundant	Common	Tolerates well a certain amount of turbidity (Laborel, 1969b) and is associated with shallow, turbid reef environments (Veron, 2000).
Mussismilia braziliensis	Main reef top builder	Not reported	Low resistance to water turbidity (Hetzel, & Castro, 1994; Laborel, 1969b; Veron, 2000).
Scolymia wellsi	Not reported	Common	Common in cryptic environments, with moderate or low light level (Laborel, 1969b).
Meandrina braziliensis	Abundant	Not reported	Low resistance to water turbidity (Hetzel, & Castro, 1994; Laborel, 1969b; Veron, 2000).
Stephanocoenia michelini	Abundant	Not reported	
Millepora alcicornis	Main reef top builder	Uncommon	
Millepora nitida	Abundant	Not reported	

Table 4. A preliminary plan of ecological reef states at Todos os Santos Bay since the Holocene

Ecological state 1 From 8 ky to 5 ky BP	Ecological state 2 After 5ky BP	Ecological state 3 1962 - 2003
Large colonies of *Mussismilia braziliensis*	Smaller colonies of *Mussismilia braziliensis*	Absence of *Mussismilia braziliensis*
Dominance of *Mussismilia braziliensis*	Changes in dominant species covering the reefs	Changes in species composition favouring *those* more adapted to turbidity and sedimentation