Chapter 27
Marine Bioinvasions in the Brazilian Coast: Brief Report on History of Events, Vectors, Ecology, Impacts and Management of Non-indigenous Species

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27.1 Introduction

The Brazilian coast extends for about 8000 km from Cape Orange (4°N) to Chui (34°S) (Fig. 27.1). This long coastline comprises a variety of ecosystems under the influence of oligotrophic waters transported by two western boundary currents, the Brazil and North Brazil currents (Stramma and England 1999), together with continental influences related to a wide spectrum of river inputs, the largest of which being the massive Amazon River plume in the north and the combination of the La Plata and Patos Lagoon outflows in the south (Castro Filho and Miranda 1998). Seasonal or intermittent intrusions of cold and nutrient-rich oceanic waters carried underneath the Brazil and North Brazil currents (the so-called South Atlantic Central Water) is another important physical forcing on regional shelf ecosystems of Brazil, particularly on the Southern Brazilian Bight and more southern areas (Lopes et al. 2006). Regionally important coastal ecosystems are (1) sandy beaches, occurring from north to south, with the largest ones in southernmost areas of the state of Rio Grande do Sul; (2) mangrove forests, which occur from the northern tip of the country to the state of Santa Catarina in the south, (3) coral reefs, ranging from Maranhão to Bahia including the largest coral reef system of the South Atlantic, the Abrolhos Reefs (Leão et al. 2003); (4) rocky shores, spread along the entire coast from the northeast to the south, but more extensive in the southeast; (5) coastal lagoons, such as the Cananéia-Iguape estuarine complex in the state of São Paulo and the Patos Lagoon in the state of Rio Grande do Sul; (6) saltmarshes, of regional importance only south of the state of São Paulo; and (7) sandy to muddy bottoms of the infralitoral realm down to the shelf break (Seeliger and Kjerfve 2000). Given such a large array of marine ecosystems and the extent of the Brazilian coastline, the country is undoubtedly a major receptor and donor of tropical and subtropical organisms in the world's oceans.

Research on marine bioinvasions is a relatively new topic in Brazil. The first comprehensive lists of introduced and invasive species are starting to be compiled and the understanding of patterns of invasion strategies is far from being accom-

G. Rilov, J.A. Crooks (eds.) *Biological Invasions in Marine Ecosystems.* Ecological Studies 204,

Fig. 27.1 Map of Brazil showing coastal states in *gray* with subdivision of tropical and subtropical zones. Acronyms for the names of the states mentioned in the text are, from north to south: Maranhão (MA), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Pernambuco (PE), Bahia (BA), Espírito Santo (ES), Rio de Janeiro (RJ), São Paulo (SP), Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RS)

plished. There is a clear trend of increasing bioinvasion events in regional coastal ecosystems, but whether invasion rates are actually increasing or are a result of more intensive research efforts in the recent past is still an open question. The data available is sparse and locally produced, that is, spatial trends might reflect specific research interests rather than actual introduction and dispersal patterns. Some temporal trends can be pointed out, however, as will be discussed below.

There is no doubt that commerce through shipping and offshore oil exploration have increased exponentially in Brazil in the last 20 years and, in fact, there is sound indication that ballast and fouling are the major vectors of some of the aliens detected (Souza and Silva 2004). Interestingly, if one goes back 10 or more years and checks the literature related to the taxonomy and distribution of Brazilian marine species, one notices that most publications considered unreported species as new occurrences of native species (see Chap.2, Carlton). Nowadays, most publications do not disregard the possibility of new occurrences as prospective alien species. Nevertheless, detailed information on possible transport vectors and their pathways are still needed to support introduction hypotheses.

Our goal in this chapter is to present our current understanding of possible trends of introduction of marine species in the Brazilian coast based on the best investigated case studies, including introduction vectors and further dispersal, information on the status of populations, actual and/or potential impacts, and management initiatives conducted so far. The locations mentioned in the text can be found in Fig. 27.1.

27.2 The Plankton Realm

27.2.1 Phytoplankton Species

Designating phytoplankton species as nonindigenous can be quite complex and controversial. Awareness of the role and risks of invasive species has led many researchers to immediately assign new reports in the cryptogenic category as a cautionary measure. For Brazilian waters, there are only three cases that hold strong evidence to support their status as introduced: the dinoflagellates *Alexandrium tamarense* (Lebour) Balech, 1992 and *Gymnodinium catenatum* Graham, 1943, and the diatom *Coscinodiscus wailesii* Gran and Angst, 1931. The sequence of events leading to their introduction, distribution and present/potential impacts on the Brazilian coast are discussed, respectively, in Persich et al. (2004), Proença et al. (2001), Fernandes et al. (2001), and summarized in Proença and Fernandes (2004).

The first record of *A. tamarense* in the western South Atlantic was in Argentina, as a coastal bloom in 1980. In 1991, the species bloomed along the Uruguayan coast, and the phenomenon was again detected in 1991, 1993, 1995 and 1996. In Brazil, it was first detected in August 1996 along Cassino Beach (state of Rio Grande do Sul). Cultures isolated from Brazilian waters showed two genetic signatures, from the eastern and western coasts of North America (Persich et al. 2004). The lack of more molecular data for populations isolated from the western South Atlantic makes difficult the interpretation of possible transport and introduction mechanisms to Brazilian waters. There are three possible, non-mutually exclusive explanations for the introduction of this species in Brazil: (1) transport by marine currents from their initial site of introduction, that is, from Argentina to Uruguay, and then to southern Brazil; (2) secondary introduction by port-hopping between these South American ports; and/or (3) direct introduction to a Brazilian port. Indeed, *A. tamarense* is a cyst-forming species and transport in ballast tanks is a likely vector. This bloom-forming species can produce toxins that may cause paralytic shellfish poisoning with impacts to mariculture activities and public health (Hallegraeff et al. 2003).

The biogeography of the early and more recent records of *Gymnodinium catenatum* is not very conclusive in tracing the history of its world-wide distribution. The earliest record was in the Gulf of California, eastern North Pacific in 1940; it was later detected in Argentina in 1962; since the 1970s, the number of records and locations increased and also include a citation for Uruguayan waters (Hallegraeff and Fraga 1998). In Brazil, it was first detected in the state of Santa Catarina in 1998, but it is also found at present in neighboring states (Paraná and São Paulo). One of the main arguments that favor the introduction hypothesis is the fact that it is a conspicuous species (large size and chain-forming) that would have hardly gone unnoticed in routine phytoplankton studies for so long. Moreover, like *A. tamarense*, it is a cyst-forming species that favor ballast tanks as a possible transport mechanism. It is also known to have caused blooms in different parts of the world, and it can produce toxins that may lead to paralytic shellfish poisoning.

Coscinodiscus wailesii is a centric diatom originally described from the Pacific coast of North America (state of Washington) in 1931. At that time, it was also recorded in several other locations along the coastline down to California, as well as in Japan. In the 1970s to 1980s, new records appeared in European and South American waters. In Brazil, its first published record was in the state of Paraná in 1983, but it is now known to be a regular component of phytoplankton populations in different locations between the states of Bahia and Rio Grande do Sul. This species is quite conspicuous in size and shape and would likely be noticed. Transport in ballast tanks is a likely vector, since *C. wailessii* can form resting cells. It has caused harmful blooms in Brazilian waters (Fernandes et al. 2001) and elsewhere (Boalch and Harbour 1977): high densities of this diatom can cause temporary exclusion of other phytoplankton species with detrimental effects to filter-feeders; it can lead to oxygen depletion that is deleterious to marine biota; and it can produce mucilage that may inhibit predation and also clog fishing nets with negative impacts on fishing activities.

27.2.2 Zooplankton Species

Six zooplankton species have been reported as non-native to Brazilian coastal waters, only three of which have widened their distribution range since initial reports (Lopes 2004). Hence, our brief account will focus on those well-established species.

The calanoid copepod *Temora turbinata* Dana, 1849 was first recorded in the Vasa-Barris estuary in the Sergipe coast in the late 1980s (Araújo and Montú 1993) and spread over southeastern (Lopes et al. 1999) and southern waters (Muxagata and Gloeden 1995), where it is currently one of the dominant pelagic copepods (Lopes et al. 2006). Its arrival at the Brazilian coast likely occurred through ballast water release, but the possibility of unintentional introduction with shrimp breed stocks brought from Southeast Asia to establish aquaculture initiatives in Northeastern Brazil in the late 1970s cannot be discounted. Before the establishment of the invasive species, *T. stylifera* (Dana, 1849) was the only representative of the genus on the Brazilian coast. However, there are no large pre-introduction datasets available to compare present and past distributions of *Temora* spp. in the region. The lack of robust historical information is a recurrent problem in building introduction and dispersion hypotheses.

Another exotic marine copepod thrives in Northeast Brazil, although at lower abundances compared to *T. turbinata*. In this case, there are more clear indications of how the introduction took place. *Pseudodiaptomus trihamatus* (Wright 1937), native to the Indo-Pacific, was first detected in shrimp ponds in the Potengí river estuary (Rio Grande do Norte) in 1977, and then subsequently found in the natural habitat under a relatively strict distribution range (Medeiros et al. 1991). The relationship of *P. trihamatus* introduction in Brazil to aquaculture is an obvious explanation because the establishment of shrimp farms at that time relied on breed stocks of *Penaeus monodon* (Fabricius, 1798) imported from Taiwan, where the copepod occurs as a natural component of the zooplankton community (Lo et al. 2004). Since the early records, *P. trihamatus* has been found in several estuarine ecosystems of the Northeastern coast from 6°19′60″S in Rio Grande do Norte to 3°02′12″S in Ceará (Medeiros et al. 2006). Additional sampling is urgently needed in estuaries of the relatively less-studied eastern coast of Brazil (state of Bahia) to determine whether the species is restricted to the presently reported locations, or is expanding its occurrence toward more southern areas. Like *Temora turbinata*, the existence of potential ecological impacts of *P. trihamatus* on native *Pseudodiaptomus* and other zooplankters from estuarine and coastal systems of Northeast Brazil remains unclear to date.

A small pelagic cladoceran, *Pleopis schmakeri* (Poppe, 1889), also native to the Indo-Pacific, was recorded by Rocha (1985) in a river estuary of southeastern Brazil, and in other inshore areas thereafter (Lopes 2004). Although not as common as the above-mentioned microcrustaceans, *P. schmakeri* has been reported at relatively high abundances in coastal and estuarine waters (Lopes 1997), suggesting a successful spread of the species in the nearshore environment, thanks to its parthenogenetic reproduction strategy and high growth rates (Onbé 1983).

Despite the fast and extensive geographical dispersion of exotic species of marine zooplankton in Brazil, which has been in effect for at least 30 years, we still know very little about their potential community and ecosystem level impacts, a picture that unfortunately mirrors the worldwide scenario (Bollens et al. 2002). Additional monitoring programs and experimental studies are needed to address the problem.

27.3 The Benthic Realm

27.3.1 Phytobenthos

Caulerpa scalpelliformis (Chlorophyta), a pantropical algae, has been reported along the tropical region of the Brazilian coast with a southern limit of distribution in the state of Espirito Santo (Mitchell et al. 1990). In 2001, *C. scalpelliformis* was found in Ilha Grande Bay, within the subtropical Southeastern Brazilian shelf (Falcão and Széchy 2005). Since then, the species spread and became dominant on the rocky and sand substrata, replacing the native species, particularly *Sargassum* spp. Significant changes in the macroalgae community structure were detected following the appearance of *C. scalpelliformis*, which reinforces its invasive character. Many possible transport vectors were suggested by the authors, including fouling, aquaculture and the aquarium trade (Falcão and Széchy 2005).

27.3.2 Zoobenthos

Most reported introductions of zoobenthic species in the Brazilian coast are considered isolated occurrences. Some species can be ranked as well-established in the country. Possible impacts of these species have not been detected and/or assessed at present. Only five species have presented evident impacts and are expanding their range: *Isognomon bicolor* (Adams 1845), *Tubastraea coccinea* Lesson 1829, *Tubastraea tagusensis* Wells 1982, *Chromonephthea braziliensis* (Ofwegen 2005), and *Charybdis helleri* (Milne-Edwards 1867). These species are highlighted below.

27.3.2.1 Bivalves

One of the most important introductions to the benthic realm was the bivalve *Isognomon bicolor*. This species, originated from the Caribbean region, was first reported for the Brazilian coast in 1994 (Domaneschi and Martins 2002). Initially, it was identified as another species (*Isognomon alatus*, recorded in Atol das Rocas in 1970) but its expansion and great abundance caused concern and detailed studies were performed. Currently, *I. bicolor* distribution extends from the Northeast to the South coast of Brazil (Domaneschi and Martins 2002). Ballast water and fouling are the suggested introduction vectors (Rocha 2002).

I. bicolor prevails in steep rocky coasts (>70°) with moderate wave exposure (Whorff et al. 1995; Domaneschi and Martins 2002). In the intertidal zone of rocky shores of the Arraial do Cabo region, state of Rio de Janeiro, the species was first observed in 1996 (Rocha 2002). Nowadays, this species is dominant in the mid-intertidal of Arraial do Cabo rocky shores and is responsible for reducing 50% of the native barnacle population, *Tetraclita stalactifera* (López 2003). This pattern of *I. bicolor* dominance is present in other rocky shores along the southeastern coast, where densities between 200 and 800 individuals/100 cm^2 can be found (Magalhães 1999; Rapagnã 2004; Breves-Ramos 2004) (Fig. 27.2). Despite its high abundance, this invasive species has not been successful in colonizing and establishing itself on bare substrate, appearing only at late succession stages in the intertidal habitat (Rocha 2002) or recruiting inside holes, crevices or other complex substrates (Moyses 2005). Recent ecological studies in Arraial do Cabo show that this alien bivalve is now part of the diet of the major predator in this habitat, the gastropod *Stramonita haemastoma* (Linnaeus, 1767) (López 2003). Although *I. bicolor* is superior to other native preys (mussels and barnacles) in caloric terms, it is not yet preferentially selected (López and Coutinho 2005). The authors suggested that 10

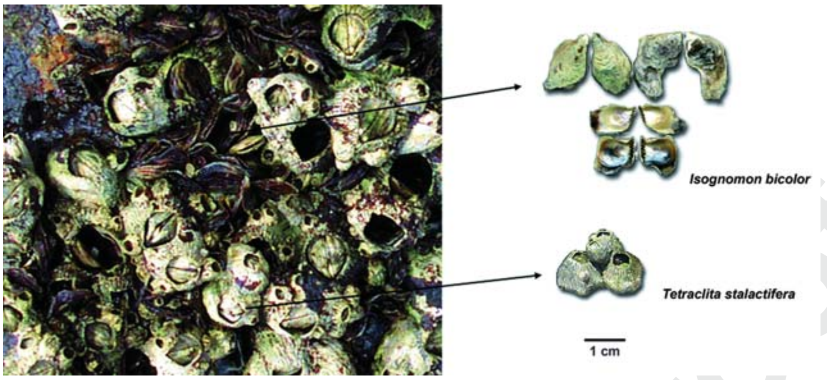

Fig. 27.2 The invasive bivalve *Isognomon bicolor* and the native barnacle *Tetraclita stalactifera* on the rocky coasts of Angra dos Reis, state of Rio de Janeiro. This invasive species is not successful in colonizing and establishing itself on bare substrate, appearing only at late succession stages in the intertidal habitat or recruiting inside holes, barnacle tests, crevices or other complex substrates. In the mesolittoral of Arraial do Cabo, state of Rio de Janeiro, it is responsible for reducing 50% of the population of *Tetraclita stalactifera*

years of establishment and trophic interactions probably are not sufficient for *I. bicolor* to be recognized as a better caloric prey and that prey manipulation is not yet efficient to compensate its consumption. The impact of predation by *S. haemastoma* on *I. bicolor* populations has not yet been investigated but it was suggested to be an important mortality factor.

The ecological impacts of *I. bicolor* have not been assessed in detail to date. This is a difficult task because little quantitative data of the pre-invasion communities is available. Nevertheless, the high densities of this species in the Brazilian coast suggest it has caused profound changes in the native rocky coast communities. Besides the competition and displacement of barnacle populations, *I. bicolor* probably competes with a commercial species of Mytilidae, *Perna perna* (Linnaeus 1758), a very abundant mussel found in the region (Rapagnã 2004; Breves-Ramos 2004). This species, native to Africa, was probably introduced between the eighteenth and nineteenth centuries during the slave trade. This hypothesis is supported by the absence of *P. perna* in prehistoric deposits of shells that are close to present-day populations (Souza et al. 2004). Nowadays, *P. perna* is completely established. Actually, it plays an important role in the community structure of rocky coasts between the states of Espírito Santo and Rio Grande do Sul. In the past, *P. perna* probably diminished the density of *Pinctata imbricata* Rodin, 1867, a very abundant bivalve in the prehistoric deposits of shells and rare at present (Rapagnã 2004).

27.3.2.2 Corals

In the subtidal zone, three exotic coral species also deserve attention because of their invasive potential and ecological significance. The first is an Alcyonacean, recently described as *Chromonephthea braziliensis* (Ofwegen 2005) whose origin is, in spite of the name, the Indo-Pacific. The species was first found approximately 15 years ago inhabiting a sand bottom on the boundary of shallow (8–10 m) rocky shores of the southeastern coast (Arraial do Cabo, state of Rio de Janeiro) (Fig. 27.3). The first scientific observations of the establishment event started with precisely eight individuals ranging from 20 to 60 cm in height (Ferreira 2003; Ferreira et al. 2004). Monitoring dives to assess abundance and size showed that, after one year, the colony had increased to about 40 individuals near the sand-rock interface and also in a direction away from the rocky shore. Although information about the reproductive biology of the coral was not assessed, the high abundance of juveniles (5 cm) near "adults" and the restricted area of their distribution highly suggest that this soft coral has expanded only by asexual reproduction modes. The mortality of young brooded monitored in the field was about 70% and exposure to water temperature < 17 °C was probably the main factor restricting the expansion of the species. Recent experiments show that this soft coral alien has chemical defenses against generalist fishes, and can also cause physical damage to other native coral species (Lages et al. 2005). Indeed, these experiments have shown that the species

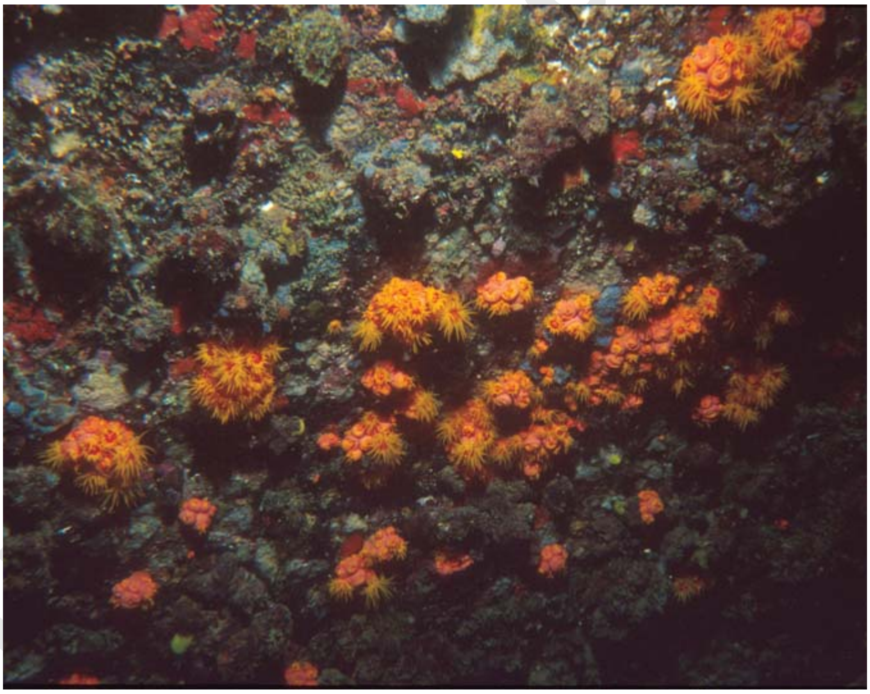

Fig. 27.3 *Tubastraea coccinia* inhabiting overhangs of rocky shores of Arraial do Cabo, state of Rio de Janeiro. Succession and competition experiments suggested the species is expanding its percent cover rapidly. Despite high diversity of benthic organisms, no other species seems to be competitively effective to preclude *T. coccinea* expansion

uses chemical defense to slowly expand its distribution in the environment. Despite such invasion potential, the distribution of *C. braziliensis* is still restricted to about a few hundred meters even though more than a decade has passed after its first discovery in Arraial do Cabo. Most colonies found 200 m away from the original dispersal point could be related to transposition by unwarned scuba divers, as the species site became a famous diving point. Their sizes (maximum 90 cm high) and habitat (sand bottom near the interface of the rocky shore) make them easy to detect and mechanically remove. Eradication in this case is controversial because this is considered a protected area by the National Environmental Agency of Brazil.

The second alien coral, *Tubastraea coccinea* (Fig. 27.4) is an azooxanthellate species that was first recorded in the mid-1980s in association with oil drilling platforms located in the Campos Basin, offshore of the northern coast of the state of Rio de Janeiro (Castro and Pires 2001). Later, in the mid-1990s, this species and also *Tubastraea tagusensis* (the third one) were recorded at Ilha Grande Bay, state of Rio de Janeiro, southward from Campos Basin (Paula and Creed 2004, 2005). More recently, *T. coccinea* was confirmed recruiting in subtidal rocky shores of Arraial do Cabo (Ferreira 2003; Ferreira et al. 2004). Today, this species has been

Fig. 27.4 *Chromonephthea brasiliensis* sharing space with *Sargassum furcatum* in unconsolidated bottom of Arraial do Cabo, state of Rio de Janeiro. This species finds better habitat in the sand interface near rocky shore, but in the past few years it began to colonize the hard substrate as well

recorded in the southeastern and southern coasts in natural rocky shores and artificial structures, and there are also some records in the northeastern coast associated with oil platforms. The suggested introduction vector is most likely fouling as the area of the first detection is a large oil exploration basin and Ilha Grande Bay is near an oil ship port. The fact that these organisms have short-lived larvae (between 3 and 14 days until final recruiting) (Reyes-Bonilla et al. 1997) does not favor ballast water as a very successful long-distance transport mechanism.

The literature describes *Tubastraea* as an asymbiotic, azooxanthellate coral, having no requirements for sunlight and consequently occurring on overhangs or drop-offs (Cairns 1994; Paula and Creed 2005). In Ilha Grande Bay, both species are abundant from very shallow (0.5–1.0 m) to deep parts of the rocky shores, prefer vertical substrata, but utilize all angles (Paula and Creed 2005). Reports from that region have shown the strong invasive potential of both *Tubastraea* species excluding other native benthic organisms, including other coral species (Creed 2006). In Arraial do Cabo, where only *T. coccinea* was recorded, the species is found recruiting only in overhangs (CELF, personal observation) and spreading over to more illuminated substrate by budding. Succession experiments have shown percent cover to increase by an average 20% per year, although three years of consecutive monitoring make evident an asymmetric growth per year (Ferreira, unpublished data). In spite of a high diversity of benthic organisms (algae, sponges, bryozoans, corals, hydrozoans, ascidians among others) on natural substrate where *Tubastraea* recruits, no species has apparently shown any competitive ability to preclude the alien expansion in subtidal rocky shores of Arraial do Cabo. Chemical defense is highly evident in the expansion phase of such species (Koh and Sweatman 2000). The expansion process of *T. coccinea* in Arraial do Cabo seems to be at least tenfold faster than that of *Chromonephthea braziliensis*. The former species is comparatively a better competitor, reproducing by either asexual or sexual modes. Its fast expansion along the coast associated with its cryptic habits (recruiting in overhangs) make an eradication program a difficult task. Like *C. braziliensis*, *Tubastraea* species are appreciated by divers, that is, they are not perceived as threats.

27.3.2.3 Crustaceans

Charybdis helleri, a portunid crab native to the Indo-West Pacific region, was first detected in the Brazilian coast in Guanabara Bay, state of Rio de Janeiro, in 1995 (Tavares and Mendonça Junior 1996). This species was probably introduced in one or more sites in the Caribbean in the mid-1980s, coming from the Mediterranean Sea where it was introduced through the Suez Canal. Therefore, it appears that the invasion into Brazilian waters was a result of secondary introduction and/or natural dispersal that followed its arrival to the American Continent. One of the possible vectors is ballast water. Nowadays, it is found from Maranhão (North) to Santa Catarina (South) (Carqueija and Gouvêa 1996; Calado 1996; Mantelatto and Dias 1999; Tavares and Mendonça Junior 2004).

C. helleri has many traits that favors the invasion of new areas: a relatively long larval life (44 days), rapid growth and maturation within about one year, ability to store sperm and produce multiple broods of high fecundity, generalized carnivorous diet, ability to explore different habitats and a cryptic behavior (protection from visual predators) (Dineen et al. 2001). On the southern Brazilian coast, populations with high densities of adults, young and ovigerous females confirm that *C. helleri* is well established (Mantelatto and Dias 1999). Ovigerous females were present throughout most of the year and the estimated size at sexual maturity was 35.0 mm of carapace width (Mantelatto and Garcia 2001). The fecundity estimated in laboratory in a female of 50.0 mm carapace width was of 47,000 zoeal stage I (Tavares and Mendonça Junior 2004).

C. helleri is of commercial interest in Southeast Asia (Lemaitre 1995) but in Brazil it has no value to fishermen. Possible impacts on native communities are still to be quantified. Although in some areas (state of São Paulo) this crab is less abundant than the native ones (Mantelatto and Fransozo 2000), in other areas (state of Bahia) it is already more abundant than the native species, *Callinectes larvatus* (Ordway, 1863) (Carqueija 2000). Furthermore, the ecological consequences of its introduction into reef habitats of the northeastern coast are yet unforeseen. It is also a potential host of the WSSV (White Spot Syndrome Virus) (Tavares and Mendonça Junior 2004). For these reasons, the expansion and relationships of this species with other brachyuran species should be closely monitored in the region (Mantelatto and Garcia 2001). The predation of *C. helleri* by a native *Octopus* species at Northeastern Brazilian reefs was recently documented. Unfortunately, the populations of this octopus species are declining due to overfishing, therefore it probably cannot serve as a controlling agent (Sampaio and Rosa 2005).

Many species of barnacles are commonly associated with fouling and probably their ranges were expanded through marine-related human activities (Young 1995). Three species of barnacles are considered introduced in the Brazilian coast. The first is *Megabalanus coccopoma* (Darwin, 1854), recorded in the 1970s in Guanabara Bay, state of Rio de Janeiro (Young 1994). Its main dispersal mode is through fouling, including ship hulls and oil platforms (Apolinário 2003). This species dominates the same zone as *M. tintinabulum* Pilsbry, 1916, a cryptogenic species found in the Brazilian coast since the beginning of the twentieth century (Apolinário 2003).

Amphibalanus reticulatus (Utinomi, 1967) is a recent introduction that is currently expanding its range in the Southwestern Atlantic. In 1990, it was first sighted in the state of Pernambuco; by 1992, it was found in the state of Bahia (Young 1995); and by 1996, in the state of Rio de Janeiro. Nowadays, it is also found in the state of Paraná (Neves 2006). The density found on port structures in Sepetiba Bay, state of Rio de Janeiro, was very high (4410 individuals/m^2). In Ilha Grande Bay, state of Rio de Janeiro, it is already the dominant species on artificial substrates (Mayer-Pinto and Junqueira 2003).

The third barnacle species is *Chirona (Striatobalanus) amaryllis* (Darwin, 1854). It was detected in 1982 in the state of Piauí (Young 1989), in 1990 in the state of Pernambuco (Farrapeira-Assunção 1990), and in 1992 in the state of Bahia

(Young 1995). Recently (2005), it was found in the state of Paraná (Neves 2006). Although this species occurs in the sub-littoral in its native area (Indo-Pacific) it was found in the intertidal area in Brazil (Young 1989).

27.4 Fishes

There are no reports on fish introductions in Brazilian coastal waters related to mariculture developments, in contrast to fresh water systems in the country (Gomiero and Braga 2004). Few records of non-native reef fish species were reported for the southeastern coast (Moura 2000), all of them based on sights of one or two individuals and considered as originated from sporadic ornamental aquarium releasing with no further possibilities of population establishment.

At least one species, *Acanthurus monrovie* Steindachner, 1876, originally only distributed in the Eastern Atlantic, was recently found (three individuals) to reach a coastal island off Santos, state of São Paulo (Luiz-Junior et al. 2004). In this case, however, the invasion mechanism was suggested as a natural dispersion, by means of planktonic larvae crossing the mid-Atlantic ridge barrier through a well known trans-Atlantic route. Actually, this route is said to function in both eastward-westward directions (Luiz-Junior et al. 2004). Recent works have genetically proven that fishes colonized both sides of the Atlantic using these routes (Bowen et al. 2001).

Two fishes that are associated with fouling in ships and oil platforms have recently been indicated as introduced species. One is the tessellated blenny, *Hypsoblennius invemar* Smith-Vaniz & Acero P., 1980, originally from Mexican Gulf to Venezuela including the lesser Antilles (Cervigon 1994). This species was reported to be associated with oil platforms in the Mexican Gulf and was first recorded in the Brazilian coast at oil platforms of the southern region (Hostim-Silva et al. 2002). Since then, the species has been found all along the south and southeastern region inhabiting empty barnacles in shallow hard substrate (Ferreira et al. 2004), the same substrate they utilize on ship and platform hulls. The other species is also a blenny, the muzzled blenny *Omobranchus punctatus* (Valenciennes, 1836), with wide-spread distribution including the Indo-Pacific, Mediterranean and some parts of the Atlantic. Recently, this species was recorded inhabiting mussel (*P. perna*) cultivation stands in the state of Santa Catarina (Gerhardinger et al. 2006) and also further north, in the states of Rio de Janeiro and Bahia (Gerhardinger et al. 2006). Cryptic fishes like blennies and gobies are predisposed to bioinvasion associated with fouling. However, their cryptic behavior makes their detection and identification a hard task. Because they seek refuge and lay eggs in small holes and empty barnacles, they are prone to inhabit artificial hard substrates like ship hulls, pilings in ports, etc. Additionally, their tolerance to salinity variations allows them to take advantage of ballast-intake holes on ship hulls and offshore oilrigs (Wonham et al. 2000). There is no doubt that these fishes are successful in “taking a ride” as fouling and travel great distances.

27.5 Intentional Introductions Related to Marine Farming

Shrimp farming remained rare in the Brazilian coastline until the mid-1980s, when substantial efforts were employed by private and public enterprises to establish a cost-effective strategy, again testing several shrimp species. Target native species including *Farfantepenaeus paulensis* (Pérez Farfante, 1967) were not productive enough and were discarded against exotic species such as *Marsupenaeus japonicus* (Bate, 1888) and *Litopenaeus vannamei* (Boone, 1931). The latter gradually proved to be the most viable species for cultivation because of its high adaptability to the varying hydrochemical conditions of the tropical estuaries of the Northeast. At the present stage, *L. vannamei* is virtually the only marine shrimp species cultivated in Brazil.

Marine shrimp farming is a growing economic activity, currently accounting for 50% of the total exportation of marine products by the country, with an average annual yield of approximately US$ 140 million for 2002–2005. However, such immediate socioeconomic benefits have obscured the environmental impacts associated with the implementation and operation of shrimp farms under non-sustainable practices. These include – but are not limited to – mangrove deforestation for the establishment of cultivation tanks, outflow of highly eutrophic effluents into natural water bodies, and the potential dissemination of shrimp virus diseases to native crustacean populations (but see Boeger et al. 2005). While an intense debate persists over environmental impacts caused by shrimp farming against actual or prospective socioeconomic benefits of the activity, an increasing number of reports on *Litopenaeus vannamei* occurrence in estuarine and coastal waters of Brazil – often at high densities – has emerged in recent years (Santos and Coelho 2002; Barreto et al. 2000; Barbieri and Melo, in press). To what extent these fugitive specimens of poorly managed shrimp farms will be able to establish self-sustaining populations in the natural environment is still an open question.

A different strategy for the intentional introduction of a marine species occurred in the case of the Indo-Pacific red alga *Kappaphycus alvarezii* (Doty) Doty ex. P. Silva 1996, cultivated for production of linear sulphated polysaccharides, the so-called carrageenins. These are employed in food products as thickening and stabilizing agents. A controlled introduction plan for *K. alvarezii* has been carried out in the southeastern coast of Brazil (Ubatuba region, state of São Paulo) since 1995. The initial Philippine propagules were brought from Japan and kept under quarantine conditions in the laboratory for 10 months before their release in cultivation structures in the field (Paula et al. 1999). Careful monitoring of the potential spread of the alga toward natural habitats continues since the initial introduction, and results obtained have shown that the Ubatuba strands were unable to thrive outside aquaculture facilities (Paula et al. 2002; Oliveira and Paula 2003; Paula and Pereira 2003). However, parallel introductions of the same species have occurred in other parts of Brazil without taking into account the same careful procedures observed in Ubatuba. The outcome is similar to that of *L. vannamei*: records of the exotic species have been reported in the natural marine environment in several regions of Brazil with the most challenging scenarios occurring again in the northeastern coast. Studies about the true establishment, dispersal rates and possible ecological impacts of *K. alvarezii* populations in those areas are still needed.

27.6 Final Remarks

Brazil was one of the six developing countries engaged in the Global Ballast Water Management Program (GloBallast) implemented from 2000 to 2004 by the International Maritime Organization together with the Global Environmental Facility and the United Nations Development Program. Several Brazilian institutions were involved in a National Task Force whose goal was to develop activities to prepare the country for the implementation of the "International Convention for the Control and Management of Ships Ballast Water and Sediments" and, thus, help minimize the transfer of harmful marine organisms (Leal Neto and Jablonski 2004). One of the initiatives of this program, which is relevant in this context, was the pilot study conducted at a demonstration site, the Port of Sepetiba, state of Rio de Janeiro, that led to two concrete outcomes: (1) the development of a port-specific bioinvasion risk assessment that included studies of shipping patterns, an environmental similarity analysis between the receiving port and donor ports and also a risk species analysis (Clarke et al. 2004); and (2) a port survey following standardized protocols (Hewitt and Martin 2001) that made possible the detection of six introduced species.

The Brazilian maritime authority has established a legal instrument, the Regulation Norman 20, to coordinate the control and management of ballast water in Brazilian ports which is in accordance with the IMO Convention. It is expected that, in the near future, the inspection and control of ballast water will be a routine and widespread activity. Nevertheless, we still do not have any legal instrument to prevent/minimize invasions by hull fouling. This vector is no doubt critical to bioinvasion worldwide and deserves special attention due to the future ban of tributyl tin (TBT), an effective biocide in anti-fouling paints. Brazilian marine biodiversity, that is still being revealed, relies on the development of an effective management system of both vectors, ballast water and hull fouling.

In addition to the GloBallast program, since 2001 the Ministry of the Environment of Brazil has funded research initiatives related to bioinvasions, two of which applied to the marine environment: (1) the ALARME project has dealt with the assessment of exotic species and the establishment of a ballast water management plan for the Port of Paranaguá, state of Paraná, one of the busiest ports in southern Brazil; and (2) the INFORME/PROBIO project has provided a comprehensive list of exotic species in coastal areas of Brazil, accompanied by a series of ecological and socioeconomic data on the various species (including their actual or potential impacts). In addition, the project has provided information on prevention and control practices under development in the country to face the problem of marine bioinvasions (MMA 2006). Along the lines discussed by Colautti and MacIsaac (2004), the INFORME/PROBIO approach was to assign exotic species recorded in Brazil to three categories (detected, established and invasive) according to their populational status following initial introduction, and to their ecological, economical or sanitary impact. Apart from probable high number of cryptogenic species, a total of 53 marine and estuarine non-indigenous species has been confirmed by this national assessment, 8 of which are within the "invasive" category (FUNDESPA 2006): *Coscinodiscus wailesii, Alexandrium tamarense* (phytoplankton), *Temora turbinata* (zooplankton), *Caulerpa scalpelliformis* (macroalga), *Charybdis hellerii, Tubastraea coccinea, T. tagusensis and Isognomon bicolor* (zoobenthos). These species are dealt with in the present chapter. Large (>1 cm) benthic animals dominate the INFORME/PROBIO list, with 34 species (64% of total).

Awareness of the impacts imposed by invasive marine species has truly increased in Brazil in the past decade, not only within academia, but also in other sectors such as environmental and public health agencies, the maritime and port authorities and the shipping industry. Although funding agencies have initiated programs geared towards marine bioinvasions, the amount of money allocated does not fulfill the needs that a comprehensive survey of the extensive Brazilian coast requires. Similarly, although the shipping industry has been directly involved in R&D issues and has provided subsidies to test the efficiency of on-route ballast exchange methods (e.g., Villac et al. 2001), initiatives of the private sector are minor. There is no system of return of revenues from shipping activities to support research about bioinvasion issues. Considering that Brazil sustains an exuberant diversity in its coastal systems that provides habitat to both tropical and subtropical components, the experience and data that can be generated by studying its extensive coastline will certainly produce knowledge to be applied elsewhere.

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