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Research article

Bivalve cultures provide habitat for exotic tunicates in southern Brazil

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Abstract

Commercial shellfish farming is increasing in Brazil to provide for the growing local and international markets. Shellfish (mussel and oyster) production in Brazil is greatest in the state of Santa Catarina where three sea ports with national and international commerce are sources of non-indigenous species (NIS) that have the potential to find suitable habitat in the shellfish farms. Here we describe the tunicate community associated with shellfish farms during the past 10 years. Survey results identified 17 species of which only one was native. Two were clearly introduced. Of the 14 species classified as cryptogenic, 10 were probably introduced. Tunicates become very abundant in farms and as a consequence farms require periodic cleaning of the shells as well as associated equipment. *Styela plicata* and *Didemnum perlucidum* are the most abundant and may become a threat to natural communities, but they are currently not found on natural substrates. *Ciona intestinalis* and *Styela clava* were not found in shellfish farms, even though *C. intestinalis*, at least, has been introduced many times in Brazil. We recommend that a public awareness program be developed to prevent colonization by *C. intestinalis* in the bivalve farms. Additionally, we emphasize that the diversity of possibly introduced species also requires close monitoring for rapidly expanding populations, since a diversity of life cycles and biological requirements also increases the probability of the appearance of a new pest.

Key words: aquaculture, Ascidiacea, ascidian, bioinvasion, mussel, nonindigenous species, oyster, Urochordata

Introduction

Bivalve farms (mussels and oysters) create complex novel substrates and communities due to the combination of bivalve shells and artificial substrates. Farms are usually located within calm bays and estuaries which are locations that provide high quality habitat for fouling organisms including introduced species. Additionally, farm structures are usually suspended and protected from predation by invertebrates and fish also providing refuge for exotic organisms such as tunicates. Recent studies indicate that shellfish farms offer substrate and habitat for many exotic species (reviewed by McKindsey et al. 2007).

Tunicates are commonly an important part of the community associated with bivalves and while they do not compete with bivalves for food (Lesser et al. 1992; Petersen 2007), they can compete for substrate space and may even cause bivalve mortality by growing over them (Igic 1972). Tunicates can also increase the weight of systems causing them to sink (Getchis 2006). Thus, tunicates may often cause severe economic losses (LeBlanc et al. 2003).

Bivalve farming is increasing rapidly in Brazil (Borghetti et al. 2003), with the state of Santa Catarina being the major producer since 1990. In the year 2005, Santa Catarina was the source of 82% of the bivalves produced in Brazil. Currently, bivalve production is located within 15 bays along 1,213 ha of coastline and provides work for 786 employees, an essentially family-owned business (Manzoni 2005). In Santa Catarina, three major ports are potential sources of non-native species: São Francisco do Sul, Itajaí, and Imbituba. Ports with international ship traffic and nearby bivalve farms offer many artificial substrates for non-native species to become established. Tunicates are very common in this fouling community and some species become very abundant. In southern Brazil, in contrast with other locations, no single species becomes dominant as seen in Prince Edward Island, Canada (LeBlanc et al. 2007; Ramsay et al. 2008). Instead, many species may increase in abundance simultaneously. In this study, we list tunicate species associated with an oyster farm and a mussel farm in the state of Santa Catarina, Brazil. We examine specifically the status (resident or introduced) of each species and their potential impact in natural communities.

Methods

Study site

The mussel farm is located on the north coast of Santa Catarina, in Armação do Itapocoroy Bay (26°46'10"S, 48°47'04"W). The mussel cultivated in this region is *Perna perna* (Linnaeus, 1758), and it was likely unintentionally introduced during the slave trade (Souza et al. 2004). Now the mussel is naturalized and occurs in the low intertidal region of rocky shores along the entire Brazilian coast. Mussels are grown on long lines characterized by a rope which is buoyed and extends horizontally near the water surface. Mussels are cultivated on 3m long vertical ropes. Armação do Itapocoroy Bay is protected from waves and receives water from the plume of the Itajai-açu River whose mouth is 20 km south. Water salinity is usually less than 34 and temperatures range from 19–28°C (Schettini et al. 1999) and water depth is 9–12 m (Marenzi et al. 2006).

The oyster farm (Fazenda Marinha Atlântico Sul) is located in Ribeirão da Ilha, Florianópolis (27°43'34"S, 48°33'51"W). The oyster, *Crassostrea gigas* (Thunberg, 1793), is also non-native and was introduced for cultivation purposes. Salinity here is 32–35, water temperature is 17–29°C and water depth is 4–6 m. Oysters are reared in suspended lantern nets, a 1.5 m long structure formed by six horizontal shelves of plastic discs (42 cm diameter) on which the oysters grow, covered by fish net (to avoid predation). Lantern nets hang side by side from 90 m long main ropes supported at the surface by buoys. At this farm, five sets of 18 main ropes occupy 21 ha.

Ascidian survey

Ascidians were collected during 1998 – 1999 and 2004 – 2007 at the mussel farm and during 2006-2007 at the oyster farm. Animals were scraped from ropes, buoys, and bivalve shells, anesthetized with menthol crystals and fixed in 4% buffered formalin. Vouchers were deposited in the Ascidiacea collection of the Zoology Department, Universidade Federal do Paraná, Brazil. Abundances were estimated according to the frequency of encounters (but sampling effort was not standardized), and species were classified as rare, common or very common.

Analysis

Historical records of tunicates in southern Brazil are few, and begin in 1945 (Van Name 1945). Species status was based on Chapman and Carlton (1994), relying largely on the criteria related to geographical distribution and restriction to artificial habitats. The criterion "extension of range after first encounter" could not be used, since old tunicate reports for the region were restricted spatially and temporally. The criterion "access to human mechanism(s) of dispersal" was used for species found on boat hulls. While we did not survey boats, we did find *Didemnum perlucidum* Monniot 1983 and *Styela plicata* (Lesueur, 1823) on hulls and so kept this criterion. The criterion "insufficient active dispersion capabilities" was not used because it is true of all ascidians. We added two criteria: "found in aquaculture in other countries" and "known to be introduced in other regions" as an evidence of transport and capacity of establishment in altered environments. All criteria were based on the studied region (Santa Catarina) and a greater number of + is associated with a greater probability of a species having been introduced.

Results

With a total of 17 tunicate species found, *Polyclinum constellatum* Savigny, 1816, *Aplidium accarense* (Millar, 1953) and *Symplegma brakenhielmi* (Michaelsen, 1904) were found only on mussels and *Polycarpa spongiabilis* Traustedt, 1883 only on oysters (Table 1). The most common species were *Styela plicata* and *Didemnum perlucidum* at both farms, but neither species was dominant.

Both *Aplidium accarense* and *Botrylloides giganteum* (Aron e Sole-Cava, 1991) occasionally formed very large colonies at both farms, while *P. spongiabilis* were also very common at the oyster farm (Table 1). Tunicates were only a part of the encrusting community, sharing space with bryozoans, hydrozoans, sponges and barnacles (the latter most diverse and abundant on mussels).

Table 1. Ascidians present on a mussel (M) and an oyster (O) farm in southern Brazil (x = rare, xx = common; xxx = very common) and their invasion status in this region.

Taxa	M	O	1[a]	2	3	4	5	6	7	8	Status[b]
Clavelinidae											
Clavelina oblonga Herdman, 1880	xx	xx	-	?	+	-	+	-	+	-	C
Holozoidae											
Distaplia bermudensis Van Name, 1902	x	x	+	?	-	+	+	-	-	-	C*
Polyclinidae											
Polyclinum constellatum Savigny, 1816	x		+	?	-	+	+	+	+	+	C*
Aplidium accarense (Millar, 1953)	xx		+	?	-	-	+	-	-	-	C*
Didemnidae											
Didemnum perlucidum Monniot 1983	xxx	xxx	?	+	+	+	+	+	-	+	C*
Trididemnum orbiculatum (Van Name 1902)	x	xx	+	?	-	-	-	-	-	-	N
Lissoclinum fragile (Van Name, 1902)	x	x	?	?	-	-	+	+	-	+	C
Diplosoma listerianum (Milne-Edwards, 1841)	xx	xx	+	?	+	+	+	+	+	+	C*
Ascidiidae											
Ascidia sydneiensis Stimpson, 1855	x	x	+	?	?	+	+	+	+	+	I
Styelidae											
Botrylloides giganteum (Aron e Sole-Cava, 1991)	xx	x	+	?	-	+	+	+	-	-	C*
Botrylloides nigrum (Herdman, 1886)	x	x	-	?	+	-	-	+	-	+	C
Symplegma brakenhielmi (Michaelsen, 1904)	x		-	?	+	-	+	+	-	+	C
Symplegma rubra Monniot, 1972	x	x	+	?	-	+	+	+	-	-	C*
Styela canopus (Savigny, 1816)	x	x	+	?	-	+	+	+	+	?	C*
Styela plicata (Lesueur, 1823)	xxx	xxx	-	+	+	+	+	+	+	+	I
Polycarpa spongiabilis Traustedt, 1883		xx	-	?	-	+	+	-	-	-	C*
Pyuridae											
Microcosmus exasperatus Heller, 1878	x	x	-	?	-	+	+	+	+	+	C*

[a]1-6 modified from Chapman and Carlton (1994): (1) not recorded before in the region; (2) access to human mechanism(s) of dispersal; (3) association with known introductions; (4) prevalence in or restriction to artificial or altered environments; (5) discontinuous or restricted regional distribution; (6) global distribution; new criteria: (7) presence in aquaculture in other countries; (8) known as introduced in other regions. + for yes, - for no, ? for unknown.

[b]Status: N = native, C = cryptogenic, C* = cryptogenic but probably introduced, I = introduced.

Only *Clavelina oblonga* Herdman, 1880, *Distaplia bermudensis* Van Name, 1902, *Trididemnum orbiculatum* (Van Name 1902) and *Symplegma rubra* Monniot, 1972 are apparently native species to the Atlantic Ocean. However, *C. oblonga* and *D. bermudensis* along with *S. rubra* have disjunct distributions and so were classified as cryptogenic in southern Brazil. Further, *S. rubra* was not found in natural substrates at Arvoredo Marine Reserve (Rocha et al. 2005a) suggesting a possible human-mediated southern extension of its distribution. *Didemnum perlucidum*, *Lissoclinum fragile* (Van Name, 1902), *Diplosoma listerianum* (Milne-Edwards, 1841), *Botrylloides nigrum* (Herdman, 1886), *Styela canopus* (Savigny, 1816) and *Microcosmus exasperatus* Heller, 1878 are cryptogenic because of their disjunct distributions either in the western Atlantic Ocean or globally (Figure 1). Introduced species found included *Ascidia sydneiensis* Stimpson, 1855 and *Styela plicata*.

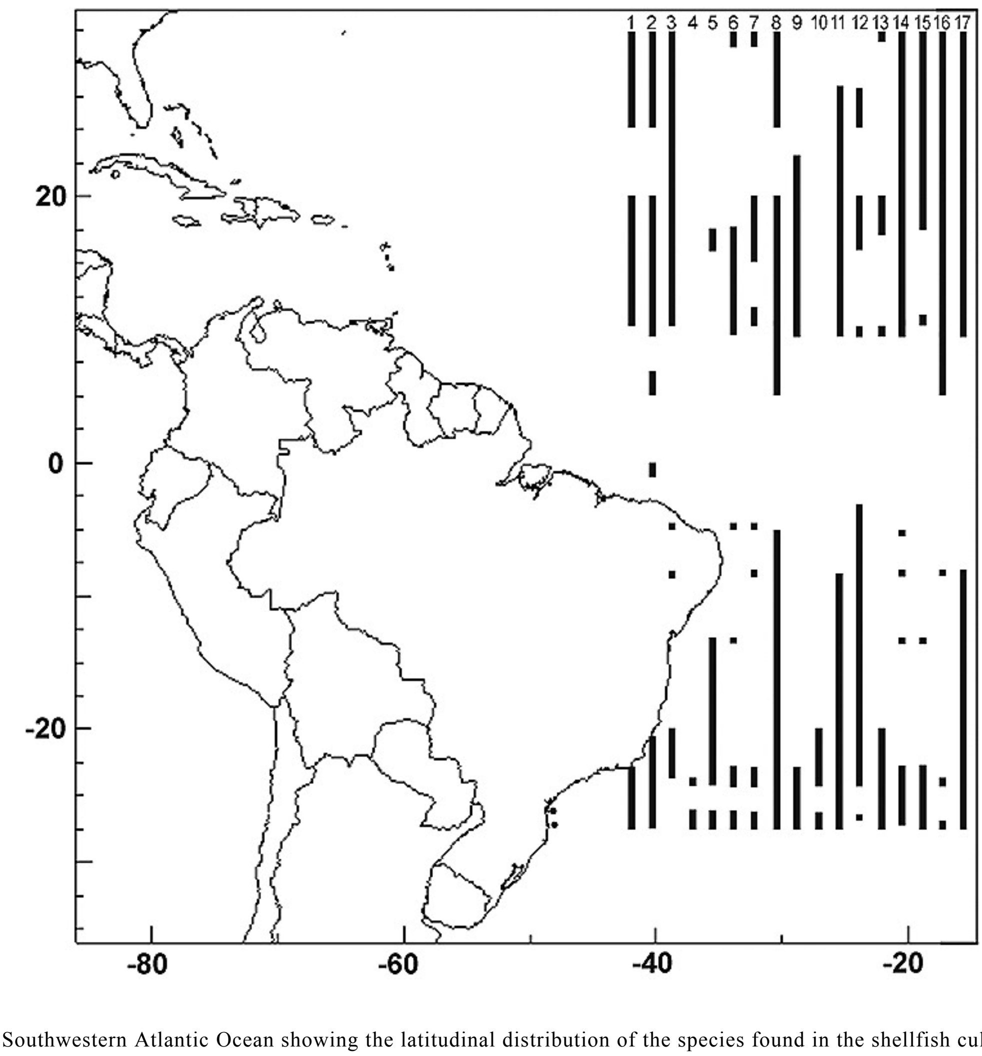

Figure 1. Southwestern Atlantic Ocean showing the latitudinal distribution of the species found in the shellfish cultures of Santa Catarina (dots on the south coast of Brazil). 1. *Clavelina oblonga*, 2. *Distaplia bermudensis*, 3. *Polyclinum constellatum,* 4. *Aplidium accarense*, 5. *Didemnum perlucidum*, 6. *Trididemnum orbiculatum,* 7. *Lissoclinum fragile*, 8. *Diplosoma listerianum,* 9. *Ascidia sydneiensis*, 10. *Botrylloides giganteum*, 11. *Botrylloides nigrum*, 12. *Symplegma brakenhielmi*, 13. *Symplegma rubra,* 14. *Styela canopus*, 15. *Styela plicata*, 16. *Polycarpa spongiabilis,* 17. *Microcosmus exasperates.*

Discussion

The dynamics of colonization and use of shellfish farm substrates by tunicates suggest that shellfish farms are potential havens for introduced and possibly invasive species. While tunicate species richness (n = 17) was low when compared to that of a nearby marine reserve (26 species, Rocha et al. 2005a) and to São Sebastião Channel, in the state of São Paulo (54 species, Rodrigues et al. 1998), this shellfish farm community comprises mostly cryptogenic species, many of which are probably introduced. The genus *Styela*, here represented by *S. plicata*, comprises very invasive species, such as *S. clava* which can reach high densities in shellfish cultures (Getchis 2006; Ramsay et al. 2008) Although records of *S. plicata* in Brazil begin in 1883 (Van Name 1945), evidence suggests that it was introduced in the south (Rocha and Kremer 2005; Barros et al. 2009) (Table 1). The oldest record for *S. plicata* in Santa Catarina is from Florianópolis in 1962 (Rodrigues 1962). The species is known to foul bivalves in Spain (Perera et al. 1990), Japan (Arakawa 1990) and Hong Kong (Huang 2003) (Table 2).

The first Brazilian record of *Clavelina oblonga* was in 1910 in São Paulo by Hartmeyer (Van Name 1945), prior to the construction of the port of São Sebastião. *Clavelina oblonga* is common along the entire southern coast of Brazil (Rodrigues et al. 1998; Rocha and Nasser 1998, Lotufo 2002, Rocha and Faria 2005, Rocha and Kremer 2005) and frequently found on continental natural rocky substrates. Since *C. oblonga* is abundant and easily identified, its absence along the northern Brazilian coast indicates a disjunct distribution, as it is also found in the Caribbean. *C. oblonga* has not yet been found in the Alcatrazes archipelago which is 36 km from the coast in São Paulo (Rocha and Bonnet, in press), while it is common on continental natural rocky substrates nearby. In Santa Catarina *C. oblonga* is often found on the natural substrates of the Arvoredo Marine Reserve, but not usually in high abundance (Rocha et al. 2005a). In São Paulo, populations decline during the winter, possibly due to mortality caused by thermal minimum of this species (R. Rocha, unpub. data).

Distaplia bermudensis is another species found along the southeastern and southern coast of Brazil (Millar 1958; Rodrigues et al. 1998, Rocha et al. 2005a; Rocha and Kremer 2005, Rocha and Costa 2005). *Distaplia bermudensis* was first recorded in 1958 by Millar and displays a continuous distribution on natural substrates from its northern limit in the state of Espírito Santo south to Paraná (Rocha and Kremer 2005). However *D. bermudensis* demonstrates a disjunct distribution with the Caribbean populations, as it is not found in Brazilian northeast coast (Figure 1). In Santa Catarina, *D. bermudensis* does not occur on natural rocky substrates and was first found in Penha, February 2004, indicating a recent extension of its distribution. *D. bermudensis* is not abundant in any region along the Brazilian coast.

Polyclinum constellatum was first found in Brazil in 1945 (in the state of Rio de Janeiro, Van Name 1945), it has one record in the state of Ceará and is common from Espírito Santo to Santa Catarina (Lotufo 2002), with the exception of Paraná (Rocha and Nasser 1998; Rocha and Faria 2005; Rocha and Kremer 2005). *Polyclinum constellatum* occurs usually in tropical waters. It was found in shellfish cultures in Hong Kong (Huang 2003, Table 2), ports in French Polynesia (Monniot et al. 1985), altered environments (e.g. shrimp farms, Monniot and Monniot 1987) and was introduced in Texas, USA (Lambert et al. 2005). The wide geographical distribution of *P. constellatum*, the absence in the oyster farm in Florianópolis and on natural substrates in Santa Catarina (Rocha et al. 2005a) suggest that this species was probably introduced in southern Brazil (Table 1), but since colonies are small and infrequent it seems that this species is not undergoing rapid establishment.

The geographical distribution of *Aplidium accarense* includes the western coast of Africa (Senegal and Monniot 1969; Lafargue and Wahl 1986; Ghana and Millar 1953) and the Brazilian coast (São Paulo, Rodrigues et al. 1998 – as *Aplidium* sp.; Santa Catarina, Rocha et al. 2005a). While little information is available describing *A. accarense* habitat in Africa, presumably this species was found in natural settings. In São Paulo and in Santa Catarina, this species occurs on natural substrates and in shellfish farms. Since localities in Africa are very tropical, *A. accarense* absence in Rio de Janeiro is surprising, since the tunicate fauna is well-known there and there are no barriers for dispersal between São Paulo and Rio de Janeiro.

Table 2. Records of locations in which tunicates form incrustations on aquaculture: M = mussels, O = oyster, P = *Pinctata*, S = scallops.

Taxa	M	O	P	S	Location	Latitude	Source
Cionidae							
Ciona intestinalis (Linnaeus, 1767)	X	X			HK, NZ, Japan, Canada. Spain, South Africa, Chile	Temp, subtr	Huang 2003, Forrest 2007, Arakawa 1990, Howes et al. 2007, Carver et al. 2003, Perera et al. 1990, Castilla et al. 2005, Ramsay et al 2008
Corellidae							
Corella eumyota Traustedt, 1882	X				NZ	Temp	Forrest 2007
Corella japonica Herdman, 1880		X			Japan	Subtr	Arakawa 1990
Ascidiidae							
Ascidia longistriata Hartmeyer, 1906	?			?	HK	Subtr	Huang 2003
Ascidiella scabra (Muller, 1776)				X	Isle of Mann	Temp	Ross et al. 2004
Ascidiella aspersa (Muller, 1776)		X			Spain	Trop	Perera et al. 1990
Perophoridae							
Perophora japonica Oka, 1927		X			Japan	Subtr	Arakawa 1990
Perophora viridis Verrill, 1871		X			Spain	Trop	Perera et al. 1990
Clavelinidae							
Clavelina lepadiformis Muller, 1776	X	X			Spain	Trop	Perera et al. 1990
Polyclinidae							
Polyclinum constellatum Savigny, 1816	?			?	HK	Subtr	Huang 2003
Aplidium densum (Giard, 1872)	X	X			Spain	Trop	Perera et al. 1990
Didemnidae							
Diplosoma listerianum (Milne-Edwards, 1841)	X	X		X	Isle of Man, Adriatic Sea, Japan, HK	Temp, Subtr	Ross et al. 2004, Igic 1972, Arakawa 1990, Huang 2003
Didemnum aspersum Tokioka 1953	?			?	HK	Subtr	Huang 2003
Didemnum sp.					Australia		Guenther et al. 2006
Didemnum vexillum Kott, 2002	X		X		USA, NZ	Temp	Bullard et al. 2007, Coutts and Forrest 2007
Trididemnum cereum (Giard, 1872)		X			Spain	Trop	Perera et al. 1990
Lissoclinum perforatum (Giard 1872)	X	X			Spain	Trop	Perera et al. 1990
Styelidae							
Botrylloides leachi (Savigny, 1816)	X	X			NZ, Spain	Temp, Trop	Forrest 2007, Perera et al. 1990
Botrylloides violaceus Oka, 1927	X	X		?	Japan, HK, USA, Canada	Subtr	Arakawa 1990, Huang 2003, Bullard et al. 2006, MacNair et al. 2007
Botryllus schlosseri (Pallas, 1766)	X				NZ, Canada	Temp	Forrest 2007, Ramsay et al. 2008
Polyandrocarpa zorritensis (Van Name, 1931)		X			Spain	Trop	Perera et al. 1990
Polycarpa pomaria (Savigny, 1816)		X			Spain	Trop	Perera et al. 1990

Table 2 (continued)

Taxa	M	O	P	S	Location	Latitude	Source
Cnemidocarpa bicornuata (Sluiter, 1900)	X				NZ	Temp	Forrest 2007
Asterocarpa humilis (Heller, 1878)		X			Chile	Temp	Castilla et al. 2005
Styela canopus (Savigny, 1816)	?			?	HK	Subtr	Huang 2003
Styela clava Herdman, 1881	X	X			Canada, Japan	Temp, Subtr	LeBlanc et al. 2007, Locke et al 2007, Bourke et al 2007, Ramsay et al 2008, Arakawa 1990
Styela plicata (Lesueur, 1823)	X	X		?	Spain, Japan, HK	Trop, Subtr, Temp	Perera et al. 1990, Arakawa 1990, Huang 2003
Styela rustica (Linnaeus, 1767)	X				Russia	Temp	Khalaman 2001
Pyuridae							
Microcosmus autralis Herdman, 1899	?			?	HK	Subtr	Huang 2003
Microcosmus exasperatus Heller, 1878		X			Spain, HK	Trop, Subtr	Perera et al. 1990, Huang 2003
Microcosmus squamiger Hartmeyer and Michaelsen, 1928		X			Mexico	Trop	Rodriguez 2005
Herdmania momus (Savigny, 1816)	?			?	HK	Subtr	Huang 2003
Pyura dura (Heller, 1877)		X			Spain	Trop	Perera et al. 1990
Boltenia echinata (Linnaeus, 1767)	X				Russia	Temp	Khalaman 2001
Molgulidae							
Molgula ficus (Macdonald, 1859)		X			Chile	Temp	Castilla et al. 2005
Molgula sp.	X				Russia	Temp	Khalaman 2001
Molgula sp	X				Canada	Temp	LeBlanc et al. 2003

NZ – New Zealand, HK – Hong Kong, ? – not clear from the reference on which culture the species was found; Temp – temperate, Subtr – subtropical, Trop – tropical

In Africa *A. accarense* absence farther south is explained by accumulation of sand and mud between the mouths of the Niger and Congo Rivers (Longhurst 2007) resulting in the reduction of adequate substrate. This evidence suggests the possibility of an introduction, however until evidence is available, we classify the species as cryptogenic.

In Brazil *Didemnum perlucidum* was first recorded in São Paulo (Rocha and Monniot 1995), is found in Bahia (Lotufo 2002), but has not been observed in Paraná or on natural substrates in Santa Catarina (Rocha et al. 2005a). *Didemnum perlucidum* is common in disturbed habitats and artificial substrates (Monniot and Monniot 1997) and is an opportunistic colonizer (L. Kremer, unpub. data). The species often forms very large colonies that grow over other organisms such as bivalves, barnacles and *S. plicata* and so it is possibly damaging the bivalve industry. Its high abundance on artificial substrates in São Paulo (Lotufo 1997) and Santa Catarina suggests invasive potential, but only small colonies in cryptic habitats occur in natural substrates. Local transportation on boat hulls was observed.

Lissoclinum fragile is found on vertical rocky walls in the Arvoredo Marine Reserve (Rocha et al. 2005a). The first record of *L. fragile* in Brazil is recent (Rodrigues et al. 1998) and its distribution along the Brazilian coast is scattered. *Lissoclinum fragile* is an abundant species in port regions, suggesting ship transport as a potential vector (Monniot et al. 1985; Rocha and Kremer 2005). Because *L. fragile* is found worldwide, it is not possible to determine its original distribution. Genetic study of this species could resolve its dispersion pattern. This species is not abundant on aquaculture equipment or bivalves.

Diplosoma listerianum is now found globally (Lambert 2001) including Brazil. A complete description of *D. listerianum* status in Brazil can be found in Rocha and Kremer (2005). The species is also found encrusting bivalve shells in other shellfish cultures (Table 2). The colonies usually stops growth at the margin of the bivalve shelves, and since it is very thin it is probably harmless to bivalve growth, but a study testing this hypothesis is still wanting.

The introduced *Ascidia sydneiensis* is only observed between Rio de Janeiro and Santa Catarina on the Brazilian coast (Figure 1) and was found in Florianópolis in 1962 (Rodrigues 1962).While rare, it is found mostly on artificial substrate (Rocha and Kremer 2005). Records worldwide include only tropical and warm temperate regions (Van Name 1945). In Penha, *A. sydneiensis* was found in 1998, only on shells of an experimental culture of *Nodipecten nodosus* (Linnaeus, 1758). In recent surveys, *A. sydneiensis* was always found inside lantern nets of both oysters and this pectinid. In the oyster culture gear, the species was abundant in early summer in lantern nets that were left submerged over four months without cleaning, but was rare on cultures during winter. *A. sydneiensis* apparently requires unoccupied space to settle, since plates with pre-existing encrusting communities deployed for another experiment were not invaded by this species during summer. While introduced, this species does not appear to be rapidly establishing in Brazilian waters.

Botrylloides giganteum on the Brazilian coast is restricted to the states of Espírito Santo, Rio de Janeiro (Aron and Sole-Cava 1991; Lotufo 2002), São Paulo (Rodrigues and Rocha 1993), and now Santa Catarina, but not Paraná (Rocha and Nasser 1998; Rocha and Faria 2005; Rocha and Kremer 2005). This species is also found in Senegal (Pérès 1949; Monniot 1969) and South Africa (Millar 1962). In both São Paulo and Santa Catarina, specimens were only found on artificial substrates. The species was not found in Penha during surveys in 1998 – 1999, or in older surveys in São Paulo and Santa Catarina (Rodrigues 1962). It is quite likely that *B. giganteum* was introduced to Brazil and that its distribution is now spreading along the coast. Colonies of *B. giganteum* may be large and thick and, if uncontrolled, this species could cause important losses to shellfish cultures, by increasing weight and smothering mussel shells.

Although *Botrylloides nigrum* occurs in the Indian and Pacific Oceans, most records suggest its original distribution is the western Atlantic (see Figure 17 in Rocha and Kremer 2005). *Botrylloides nigrum* usually grows on other organisms (Rodrigues and Rocha 1993), both animals and plants, and we observed that it can be transported by hull fouling. This species is also common on artificial substrates such as ship wrecks and PVC structures (R. Rocha, pers. obs.), although not yet reported on other shellfish culture gear as observed for other species of the Botryllinae (Table 2). Colonies are very thin and delicate suggesting that they do not harm bivalves, unless in very high densities, but this hypothesis needs to be tested.

Symplegma brakenhielmi is observed in natural and artificial substrates along the Brazilian coast, from Paraíba to Santa Catarina (Rodrigues et al 1998; Lotufo 2002; Rocha and Faria 2005; Rocha et al 2005). This species has a wide geographical distribution, with most of the records from the Indian and the Pacific Ocean under the name *S. oceanica* (Kott 1985; Monniot and Monniot 1997). In the Atlantic it has also been confounded with *S. viride*, which does not occur in Brazil (Couto 2003).

Symplegma rubra has a scattered distribution (Rocha and Kremer 2005) even in the Caribbean where it is well known (Rocha et al. 2005b). In Brazil, the northernmost record was in Espírito Santo until 2002 (Lotufo 2002). Recently *S. rubra* was reported on rocks in the intertidal region in Paraíba (Gama et al. 2006) and in Baía de Todos os Santos, Bahia on riprap during surveys in 1999 and 2004 (R. Rocha, unpub. data). If these are new arrivals or rather fortuitous findings of a rare species is difficult to say. *Symplegma rubra* is not abundant on shellfish farms in Santa Catarina and did not appear in the survey of 1998-1999. It was also not found on natural substrates of Arvoredo Marine Reserve (Rocha et al. 2005a), all suggesting a possible recent introduction.

Styela canopus is found in Brazil from Rio Grande do Norte to Santa Catarina (Rocha and Kremer 2005), but is never highly abundant and is typically associated with altered environments including artificial substrates (Rocha and Kremer 2005). This species has been reported in shellfish farms in Hong Kong (Huang 2003) (Table 2).

The first report of *Polycarpa spongiabilis* in Brazil, Rio de Janeiro, was by Traustedt (1883), who described a specimen collected in 1836 (Van der Sloot 1969). The next record of *P. spongiabilis* (as *P. obtecta*) was in 1945 from São Sebastião, São Paulo and São Francisco, Santa Catarina (Van Name 1945). This species today is also found in tropical Pernambuco (Lotufo 2002) and Bahia (R. Rocha, unpub. data) and is very common in the Caribbean (Van der Sloot 1969; Rocha et al. 2005b), which suggests a possible tropical origin. Our observations support this hypothesis as this species appeared on experimental plates in Florianópolis only during the summer, when surface water temperature peaked at 29°C. *Polycarpa spongiabilis* was unexpected in Florianópolis and it was probably introduced. This species has not been reported on bivalve farming in other countries, but two other species of *Polycarpa* have been known to encrust shellfish cultures in Spain (Table 2).

Microcosmus exasperatus has been documented from Pernambuco (Millar 1977) to Santa Catarina (Lotufo 2002) in Brazil, but is rare south of São Paulo, even in ports and shellfish farms. Its geographical distribution suggests that it originates from tropical and subtropical waters (Rocha and Kremer 2005) and that Santa Catarina is the southern limit of its distribution where the species appears on both shellfish farms and natural substrates (Rocha et al. 2005a). This species has been observed in oyster farms in the Mediterranean (Perera et al. 1990) and in Hong Kong (Huang 2003) (Table 2). In the Mediterranean *M. exasperatus* was introduced in or before 1963 (Monniot 1981).

Some surprising absences of species are notable including *Ciona intestinalis* and *Styela clava*. These species are often significant fouling species in shellfish farms and have been found to occupy nearly 100% of the available substrate at times (Howes et al. 2007; LeBlanc et al. 2007; Ramsay et al 2008). Even though bivalve farms in Brazil are subtropical and fouled by a diverse community of exotic species, neither of these species were found in this study. However, *C. intestinalis* was found in São Paulo (Rodrigues et al. 1998) and Paraná (sample from 1968 in the Ascidiacea collection of Zoology Department, Universidade Federal do Paraná – DZUP CION01), and has become established in Rio de Janeiro between 1960-80 (A. Junqueira, personal communication). *Ciona intestinalis* was also recently found in the Alcatrazes Archipelago, São Paulo (Rocha and Bonnet, in press). Thus, *C. intestinalis* has been transported to the Brazilian coast and has established many times suggesting that future establishment in Santa Catarina is likely.

Although many of the species reported here are now apparently harmless, they pose a potential threat to the shellfish culture industry and to native communities, since any change of environmental conditions could trigger exponential population growth. For example, exotic tunicate reproduction and growth has been shown to be favored due to warming of coastal waters in a temperate region (Stachowicz et al. 2002). Many of the species found in this study are apparently tropical and would be favored by an increase in water temperatures expected due to global warming.

Risk analysis (RA) is an important tool for designing and justifying management actions (McKindsey et al. 2007). We are not aware of any risk analysis for bioinvasions in the state of Santa Catarina. Therefore, a risk analysis to examine the risks of species introductions at each phase of bivalve culture and protocols to minimize introductions in this region are needed. While the invasive *Ciona intestinalis* and *Styela clava* are yet to be found in these waters, *C. intestinalis* has arrived many times in Brazil and a campaign toward public awareness is imperative to prevent its colonization of bivalve farms. Also, the diversity of introduced species in Brazil also requires constant monitoring for rapid population expansion as the diversity of life history and biological settings increases the probability of the appearance of a new pest.

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References

Arakawa KY (1990) Competitors and fouling organisms in the hanging culture of the pacific oyster, *Crassostrea gigas* (Thunberg). *Marine Behaviour and Physiology* 17: 67–94, doi:10.1080/10236249009378759

Aron S, Sole-Cava A (1991) Genetic evaluation of the taxonomic status of two varieties of the cosmopolitan ascidian *Botryllus niger* (Ascidiaceae: Botryllidae) *Biochemical Systematics and Ecology* 19(4): 271-276, doi:10.1016/0305-1978(91)90014-Q

Barros RC, da Rocha RM, Pie MR (2009) Human-mediated global dispersion of *Styela plicata* (Tunicata, Ascidiacea). *Aquatic Invasions* 4: 45-57, doi:10.3391/ai.2009.4.1.4

Borghetti NR, Ostrensky B, Borghetti, JRA (2003) Aqüicultura: uma visão geral sobre a produção de organismos aquáticos no Brasil e no mundo. Curitiba:

Grupo Integrado de Aqüicultura e Estudos Ambientais, 129 pp

Bourque D, Davidson J, MacNair NG, Arsenault G, Leblanc AR, Landry T, Miron G (2007) Reproduction and early life history of an invasive ascidian *Styela clava* Herdman in Prince Edward Island, Canada. *Journal of Experimental Marine Biology and Ecology* 342: 78-84, doi:10.1016/j.jembe.2006.10.017

Bullard SG, Whitlatch RB, Shumway SE, Osman RW (2006) Scientists crying foul: sea squirts are invading Long Island Sound! *Wrack Lines* 5: 2-6

Bullard SG, Lambert G, Carman MR, Byrnes J, Whitlatch RB, Ruiz G, Miller RJ, Harris L, Valentine PC, Collie JS, Pederson J, McNaught DC, Cohen AN, Asch RG, Dijkstra J, Heinonen K (2007) The colonial ascidian *Didemnum* sp. A: Current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. *Journal of Experimental Marine Biology and Ecology* 342: 99-108, doi:10.1016/j.jembe.2006.10.020

Carver CE, Chisholm A, Mallet AL (2003) Strategies to mitigate the impact of *Ciona intestinalis* (l.) biofouling on shellfish production. *Journal of Shellfish Research* 22: 621-631

Castilla JC, Uribe M, Bahamonde N, Clarke M, Desqueyroux-Faúndez R, Kong I, Moyano H, Rozbaczylo N, Santelices B, Valdovinos C, Zavala P (2005) Down under the southeastern Pacific: a survey of marine non-indigenous species in Chile. *Biological Invasions* 7: 213-232, doi:10.1007/s10530-004-0198-5

Chapman JW, Carlton JT (1994) Predicted discoveries of the introduced isopod *Synidotea laevidorsalis* (Miers, 1881). *Journal of Crustacean Biology* 14(4): 700-714, doi:10.2307/1548863

Couto ACF (2003) Estudo taxonômico das ascídias do gênero *Symplegma* (Tunicata, Ascidiacea, Styelidae) encontradas no canal de São Sebastião, SP. Master Thesis, Universidade de São Paulo

Coutts ADM, Forrest BM (2007) Development and application of tools for incursion response: lessons learned from de management of the fouling pest *Didemnum vexilum*. *Journal of Experimental Marine Biology and Ecology* 342: 154-162, doi:10.1016/j.jembe.2006.10.042

Forrest BM, Hopkins GA, Dodgshun TJ, Gardner JPA (2007) Efficacy of acetic acid treatments in the management of marine biofouling. *Aquaculture* 262: 319-332, doi:10.1016/j.aquaculture.2006.11.006

Gama PB, Leonel RMV, Hernández MIM, Mothes B (2006) Recruitment and colonization of colonial ascidians (Tunicata: Ascidiacea) on intertidal rocks in Northeastern Brazil. Iheringia, *Série Zoologia* 96(2): 165-172

Getchis TS (2006) What's putting some aquaculturists in a "foul" mood. *Wrack Lines* 5: 8-10

Guenther J, Southgate PC, Nys R (2006) The effect of age and shell size on accumulation of fouling organisms on the Akoya pearl oyster *Pinctada fucata* (Gould). *Aquaculture* 253: 366-373, doi:10.1016/j.aquaculture.2005.08.003

Howes S, Herbinger CM, Darnell P, Vercaemer B (2007) Spatial and temporal patterns of recruitment of the tunicate *Ciona intestinalis* on a mussel farm in Nova Scotia, Canada. *Journal of Experimental Marine Biology and Ecology* 342: 85-92, doi:10.1016/j.jembe.2006.10.018

Huang Z (2003) Marine biofouling in Hong Kong: a review. *Acta Oceanologica Sinica* 22(3): 467-482

Igic Lj (1972) The synascidian *Diplosoma listerianum* (M._Edw.) as epibiont on mussels (*Mytilus galloprovinciallis* Lmk) and oysters (*Ostrea edulis* L.) in the north Adriatic. *Thalassia Jugoslavica* 8: 215-230

Khalaman VV (2001) Fouling communities of mussel aquaculture installations in the White Sea. Russian *Journal of Marine Biology* 27(4): 227-237, doi:10.1023/A:1011963303073

Kott P (1985) The Australian Ascidiacea - Phlebobranchia and Stolidobranchia. *Memoirs of the Queensland Museum* 23: 1-440

Lafargue F, Wahl M (1986-1987). Contribution to the knowledge of littoral ascidians (Ascidiacea, Tunicata) of the Senegalese coast. *Bulletin de l'Institute Fondamental d'Afrique Noire, serie A, Sciences Naturelles* 46(3-4): 385-402

Lambert G (2001) A global overview of ascidians introductions and their possible impact on the endemic fauna. In: Sawada H, Yokosawa H, Lambert CC (eds) The Biology of Ascidians, Springer Verlag, Tokyo, pp 249-257

Lambert G, Faulkes Z, Lambert CC, Scofield VL (2005) Ascidians of South Padre Island, Texas, with a key to species. *Texas Journal of Science* 57(3): 251-262

LeBlanc AR, Landry T, Miron G (2003) Fouling organisms of the blue mussel *Mytilus edulis*: Their effect on nutrient uptake and release. *Journal of Shellfish Research* 22: 633-638

LeBlanc N, Davidson J, Tremblay R, McNiven M, Landry T (2007) The effect of anti-fouling treatments for the clubbed tunicate on the blue mussel, *Mytilus edulis*. *Aquaculture* 264: 205-213, doi:10.1016/j.aquaculture.2006.12.027

Lesser MP, Shumway SE, Cucci T, Smith J (1992) Impact of fouling organism on mussel rope culture: interspecific competition for food among suspension-feeding invertebrates. *Journal of Experimental Marine Biology and Ecology* 165: 91-102, doi:10.1016/0022-0981(92)90291-H

Locke A, Hanson JM, Ellis KM, Thompson J, Rochette R (2007) Invasion of the southern Gulf of St. Lawrence by the clubbed tunicate (*Styela clava* Herdman): potential mechanisms for invasions of Prince Edward Island estuaries. *Journal of Experimental Marine Biology and Ecology* 342: 69-77, doi:10.1016/j.jembe.2006.10.016

Longhurst A (2007) Ecological Geography of the sea. 2rd ed. Elsevier Academic Press, Burlington

Lotufo TMC (1997) Ecologia das ascídias da Baía de Santos (SP): período reprodutivo, crescimento e aspectos sucessionais. Master Thesis, Universidade de São Paulo

Lotufo TCM (2002) Ascidiacea (Chordata: Tunicata) do litoral tropical brasileiro. Thesis, Universidade de São Paulo

MacNair N, Mills C, Gillis B, Smith M, Landry T, Locke A, Smith A, Davidson J, Warris P (2007) History of the tunicate invasions in PEI, their impact on the cultured mussel industry and mitigation strategies employed since 1998. In: Carman M (ed) Proceeding of International Invasive Sea Squirt, PEI, Canada, 2007

Manzoni GC (2005) Cultivo de mexilhões *Perna perna*: evolução da atividade no Brasil e avaliação econômica da realidade de Santa Catarina. Thesis, Universidade Estadual Paulista

Marenzi AWC, Gesner AF, Almeida TCM, Corbeta R (2006) Comunidade macrobentônica da Armação do Itapocoroy, Penha, SC. In: Branco JO, Marenzi AWC (eds), Bases ecológicas para um desenvolvimento

sustentável: estudos de caso em Penha, SC. Editora Univali, Itajaí
McKindsey CW, Landry T, O'beirn FX, Davies IM (2007) Bivalve aquaculture and exotic species: a review of ecological considerations and management issues. *Journal of Shellfish Research* 26(2): 281-294, doi:10.2983/0730-8000(2007)26[281:BAAESA]2.0.CO;2
Millar RH (1953) On a collection of ascidians from the Gold Coast. *Proceedings of the Zoological Society London* 123 (2): 277-325
Millar RH (1958) Some ascidians from Brazil. *Annals and Magazine of Natural History* 13: 497-514
Millar RH (1962) Further descriptions of South African ascidians. *Annals of the South African Museum* 46(7): 113-221
Millar RH (1977) Ascidians (Tunicata: Ascidiacea) from the Northern and North-eastern Brazilian Shelf. *Journal of Natural History* 11: 169-223, doi:10.1080/00222937700770131
Monniot C (1969) Sur une collection d'ascidies de Dakar (Phlébobranches et Stolidobranches). *Bulletin du Muséum National d'Histoire Naturelle, série* 2 41(3): 622-654
Monniot C (1981) Apparition de l'ascidie *Microcosmus exasperatus* dans les ports mediterranéens. *Tethys* 10 (1):59-62
Monniot C, Monniot F (1987) Les Ascidies de Polynésie française. *Mémoires du Muséum National d'Histoire Naturelle* 136: 1-155
Monniot C, Monniot F (1997) Record of ascidians from Bahrain, Arabian Gulf with three new species. *Journal of Natural History* 31: 1623-1643, doi:10.1080/00222939700770871
Monniot C, Monniot F, Laboute P (1985) Ascidies du port de Papeete (Polynesie française): relations avec le milieu naturel et apports intercontinentaux par la navigation. *Bulletin du Muséum National d'Histoire Naturelle* 7 (3): 481-495
Perera M, Ballesteros M, Turon X (1990) Estudios de los organismos epibiontes en un cultivo de bivalvos marinos del delta del Ebro. *Cahiers de Biologie Marine* 31: 385-399
Pérès JM (1949) Contribution à l'étude des ascidies de la côte occidentale d'Afrique. *Bulletin de l'Institute Fondamental d'Afrique Noire* 11(1-2): 159-207
Petersen J K (2007) Ascidian suspension feeding. *Journal of Experimental Marine Biology and Ecology* 342: 127-137, doi:10.1016/j.jembe.2006.10.023
Ramsay A, Davidson J, Landry T, Arsenault G (2008) Process of invasiveness among exotic tunicates in Prince Edward Island, Canadá. *Biological Invasions* 10: 1311-1316, doi:10.1007/s10530-007-9205-y
Rocha RM, Bonnet NYK (2008) Levantamento de ascídias (Tunicata: Ascidiacea) introduzidas no Arquipélago de Alcatrazes, SP. Iheringia, Série Zoologia (in press)
Rocha RM, Costa LVG (2005) Ascidians from Arraial do Cabo, RJ, Brazil. *Iheringia, Série Zoologia* 95 (1): 57-64
Rocha RM, Faria SB (2005) Ascidians at Currais islands, Paraná, Brazil: taxonomy and distribution. *Biota Neotropica* 5(2): 1-20, doi:10.1590/S1676-06032005000300013
Rocha RM, Kremer LP (2005) Introduced Ascidians in Paranaguá Bay, Paraná, southern Brazil. *Revista Brasileira de Zoologia* 22 (4): 1170-1184, doi:10.1590/S0101-81752005000400052
Rocha RM, Monniot F (1995) Taxonomic and ecological notes on some *Didemnum* species (Ascidiacea, Didemnidae) from São Sebastião Channel, South-Eastern Brazil. *Revista Brasileira de Biologia* 55(4): 639-649
Rocha RM, Nasser CM (1998) Some ascidians (Tunicata, Ascidiacea) from Paraná State, Southern Brazil. *Revista Brasileira de Zoologia* 15: 633-642, doi:10.1590/S0101-81751998000300009
Rocha RM, Moreno TR, Metri R (2005a) Ascídias (Tunicata, Ascidiacea) da Reserva Biológica Marinha do Arvoredo, Santa Catarina, Brasil. *Revista Brasileira de Zoologia* 22(2): 461-476, doi:10.1590/S0101-81752005000200024
Rocha RM, Faria SB, Moreno TR (2005b) Ascidians from Bocas del Toro, Panamá. I. Biodiversity. *Caribbean Journal of Science* 41(3): 600-612
Rodrigues SA (1962) Algumas ascídias do litoral sul do Brasil. *Boletim da Faculdade de Filosofia, Ciências e Letras Universidade de São Paulo, Série Zoologia* 24: 193-216
Rodrigues SA, Rocha RM (1993) Littoral compound ascidians (Tunicata) from São Sebastião, estado de São Paulo, Brazil. *Proceedings of the Biological Society of Washington* 106 (4): 728-739
Rodrigues SA, Rocha RM, Lotufo TMC (1998) Guia Ilustrado para Identificação das Ascídias do Estado de São Paulo. FAPESP, São Paulo
Rodriguez, LF (2005) Novel habitats created by non-indigenous species: the role of oysters and ascidians as biological substrata for fouling communities. In: Carman M (ed) Proceeding of International Invasive Sea Squirt, Woods Hole, Massachusetts, 2005
Ross KA, Thorpe JP, Brand AR (2004) Biological control of fouling in suspended scallop cultivation. *Aquaculture* 229: 99-116, doi:10.1016/S0044-8486(03)00328-4
Schettini CAF, Carvalho JLB, Truccolo EC (1999) Aspectos hidrodinâmicos da Enseada da Armação de Itapocoroy, SC. *Notas Técnicas da FACIMAR* 3: 99-109
Souza RCCL, Fernandes FC, Silva EP (2004) Distribuição atual do mexilhão *Perna perna* no mundo: um caso recente de bioinvasão. In: Silva JSV, Souza RCCL (eds) Água de lastro e bioinvasão. Interciência, Rio de Janeiro
Stachowicz JJ, Terwin JR, Whitlatch RB, Osman RW (2002) Linking climate change and biological invasions: ocean warming facilitates nonindigenous species invasions. *Proceedings of the National Academy of Sciences of the United States of America* 6: 15497-15500, doi:10.1073/pnas.242437499
Van der Sloot CJ (1969) Ascidians of the family Styelidae from the Caribbean. *Studies on the Fauna of Curacao and other Caribbean Islands* 30 (110): 1-57
Van Name WG (1945) The North and South American ascidians. *Bulletin of the American Museum of Natural History* 84: 1-476