Aquatic Invasions (2011) Volume 6, Issue 4: 371–380
doi: 10.3391/ai.2011.6.4.02

Proceedings of the 3rd International Invasive Sea Squirt Conference, Woods Hole, USA, 26–28 April 2010

Research Article

Ascidians at the Pacific and Atlantic entrances to the Panama Canal

Mary R. Carman[1]*, Stephan G. Bullard[2], Rosana M. Rocha[3], Gretchen Lambert[4], Jennifer A. Dijkstra[5], James J. Roper[6], Anne Goodwin[7], Mimi M. Carman[8] and Elisabete M. Vail[9]

[1]*Biology Dept., Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA*
[2]*Biology Dept., University of Hartford, Hillyer College, West Hartford, CT 06117, USA*
[3]*Zoology Dept., Universidade Federal do Paraná, Curitiba, PR, Brasil*
[4]*University of Washington Friday Harbor Laboratories, Friday Harbor, WA 98250, USA*
[5]*Wells National Estuarine Research Reserve, 342 Laudholm Farm Road, Wells, ME 03090, USA*
[6]*Ecology Program, Universidade Federal do Paraná, Curitiba, PR, Brasil*
[7]*Biology Dept., Massachusetts College of Liberal Arts, North Adams, MA 01247, USA*
[8]*University of Massachusetts-Dartmouth, 285 Old Westport Rd, North Dartmouth, MA 02747, USA*
[9]*Computer Science Dept., Simmons College, 300 Fenway St., Boston, MA 02115, USA*

E-mail: mcarman@whoi.edu (MRC), bullard@hartford.edu (SGB), rmrocha@ufpr.br (RMR), glambert@fullerton.edu (GL), dijkstra@wellsnerr.org (JAD), jjroper@gmail.com (JJR), Anne.Goodwin@mcla.edu (AG), mcarman@umassd.edu (MMC), elisabete.vail@gmail.com (EMV)

**Corresponding author*

Received: 4 January 2011 / Accepted: 16 June 2011 / Published online: 12 August 2011

Editor's note:
This paper is a contribution to the proceedings of the 3rd International Invasive Sea Squirt Conference held in Woods Hole, Massachusetts, USA, on 26–28 April 2010. The conference provided a venue for the exchange of information on the biogeography, ecology, genetics, impacts, risk assessment and management of invasive tunicates worldwide.

Abstract

The Panama Canal region is susceptible to non-native species introductions due to the heavy international shipping traffic through the area. Ascidian introductions are occurring worldwide but little is known about introductions at the Panama Canal. Surveys were conducted in 2002, 2008, and 2009 within the Pacific and Atlantic entrances to the canal. We found a high diversity of ascidians on both sides of the canal, dominated by non-native species; six species occurred at both Pacific and Atlantic Panama sites. This is the first report of *Polyandrocarpa anguinea* and *P. sagamiensis* in Atlantic Panama waters and *Ascidia incrassata, Ascidia sydneiensis, Botrylloides nigrum, Botryllus planus, Didemnum perlucidum, Diplosoma listerianum, Microcosmus exasperatus, Polyandrocarpa zorritensis, Polyclinum constellatum, Symplegma brakenhielmi, Symplegma rubra,* and *Trididemnum orbiculatum* in Pacific Panama waters. The canal may serve as a major invasion corridor for ascidians and should be monitored over time.

Key words: Panama Canal, tunicates, shipping traffic, species introductions, tropics

Introduction

The narrow isthmus of Central America separates the Pacific and Atlantic Oceans and the Panama Canal has provided intra-oceanic passage for commercial and recreational ships for almost a century. In October 2010, the Panama Canal Authority celebrated the passage of one million ships through the canal since it opened in 1914. Due to the heavy international shipping traffic through the area, the Panama Canal region is susceptible to non-native species introductions. Shipping (e.g., ship hulls, ballast water, sea chests) provides vectors and dispersal mechanisms for non-indigenous species (Coutts and Dodgshun 2007; Minchin et al. 2009), including ascidians. Cohen (2006) documented the presence of non-native invertebrates at the Panama Canal, including the ascidians *Botryllus schlosseri* (Pallas, 1766) on the Pacific side of the canal and *Botrylloides perspicuum* Herdman, 1886, *Cnemidocarpa irene* (Hartmeyer, 1906), *Diplosoma virens* (Hartmeyer, 1909), and *Polyandrocarpa zorritensis* (Van Name, 1931) on the Atlantic side of the canal.

Transport of exotic species around the world is increasing due to increased activities associated with international trade and movement of people (Cohen 1999), and an increased volume of shipping traffic is concentrated at canal zones (Cohen 2006). Ascidian introductions are occurring worldwide but little is known about introductions at the Panama Canal. Ascidians are highly invasive (Lambert and Lambert 2003; Lambert 2007, 2009) and recent appearances of exotic ascidian species around the world have caused significant ecological and economic damage (Coutts and Sinner 2004; Bullard and Carman 2009; Carman et al. 2010).

The ascidian fauna in Atlantic Panama waters, specifically at Bocas del Toro, has been well documented (Rocha et al. 2005). However, there is no published report of ascidians in the region around the Atlantic entrance to the Panama Canal. Previous ascidian work in the Pacific Panama area is similarly limited. Van Name (1945) documented eight species in Pacific Panama waters and Tokioka (1971, 1972) documented 13 species in neighboring Pacific Costa Rica waters (Table 1). The only analysis of ascidian faunal composition conducted concurrently on both sides of the Panama Canal was a brief rapid assessment survey (RAS) in 2002; the ascidian data are published in full here for the first time. Because the Panama Canal is a critical link to global trade, the canal likely acts as a pathway for ascidian transport. Baseline data on regional ascidian populations provide a foundation for further ecological research of ascidian populations. Therefore, we identified ascidian species on both sides of the canal.

Panama's climate is humid-tropical with marked seasonality, including a dry season (mid December to mid April) and rainy season (mid April to mid December) (Guzman et al. 2004). The Bay of Panama on the Pacific side is an area of seasonal upwelling, large freshwater runoff and high concentrations of inorganic nutrients and plankton (D'Croz et al. 2005). The greater tidal range, wider annual temperature range, and seasonal salinity changes on the Pacific side of the canal may impact subtidal fauna (Cohen 2006). In contrast, the Caribbean coast has more stable oceanographic conditions, small tidal range (<0.5 m), less turbidity and lower concentrations of dissolved nitrate and phosphate (D'Croz and Robertson 1997).

Methods

Surveys were conducted in 2002, 2008, and 2009 at several sites within the Pacific and Atlantic entrances to the Panama Canal (Figure 1). We explored 16 sites (Appendices 1–2) that represented 118 km (74 miles) of Pacific coastline and 109 km (68 miles) of Atlantic coastline and surveyed natural and artificial substrates in shallow waters (<3 m) in different habitats either by walking access or through the use of small coastal research vessels and snorkeling. Each station was surveyed for approximately two hours. All substrates at the surveyed sites were equally searched and when appropriate, small rocks were overturned and examined. Representative ascidian individuals were photographed *in situ*, collected, preserved in formalin, and identified. Voucher specimens are housed at Universidade Federal do Paraná with R. Rocha. Latitude and longitude were recorded for each site with a hand held GPS unit. Salinity was measured at the surface with a refractometer (Atago S–10). The ascidian fauna of the Atlantic Panama Canal is likely more diverse than reflected in our surveys because access to Atlantic sites was limited; due to political instability in the area and upon the advice of our guide, we only surveyed at sites on the Atlantic side of the canal that were deemed safe.

Results

We found ascidians attached to bricks, rocks, corals, bivalves, barnacles, mangrove roots, docks, pilings, mooring lines, and a shipwreck in subtidal shallow waters. No ascidians were observed in intertidal habitats. Salinity measurements at sites where ascidians were present ranged from 28 to 36 psu. At the Pacific entrance to the Panama Canal we found 20 taxa: 17 identified species (3 native, 7 introduced, 7 cryptogenic species), a presumed new species (*Ascidia* sp.), and two taxa identified only to genus (*Botrylloides* sp. and *Didemnum* sp.). At the Atlantic entrance to the Panama Canal we found 19 taxa: 18 identified species (6 native, 2 introduced, 10 cryptogenic species) and an unidentified species (*Didemnum* sp. white with green algae).

Of the 22 species previously found in the Pacific waters of Costa Rica and Panama (Table 1) (some of which were dredged in deeper waters), six were found in our shallow water

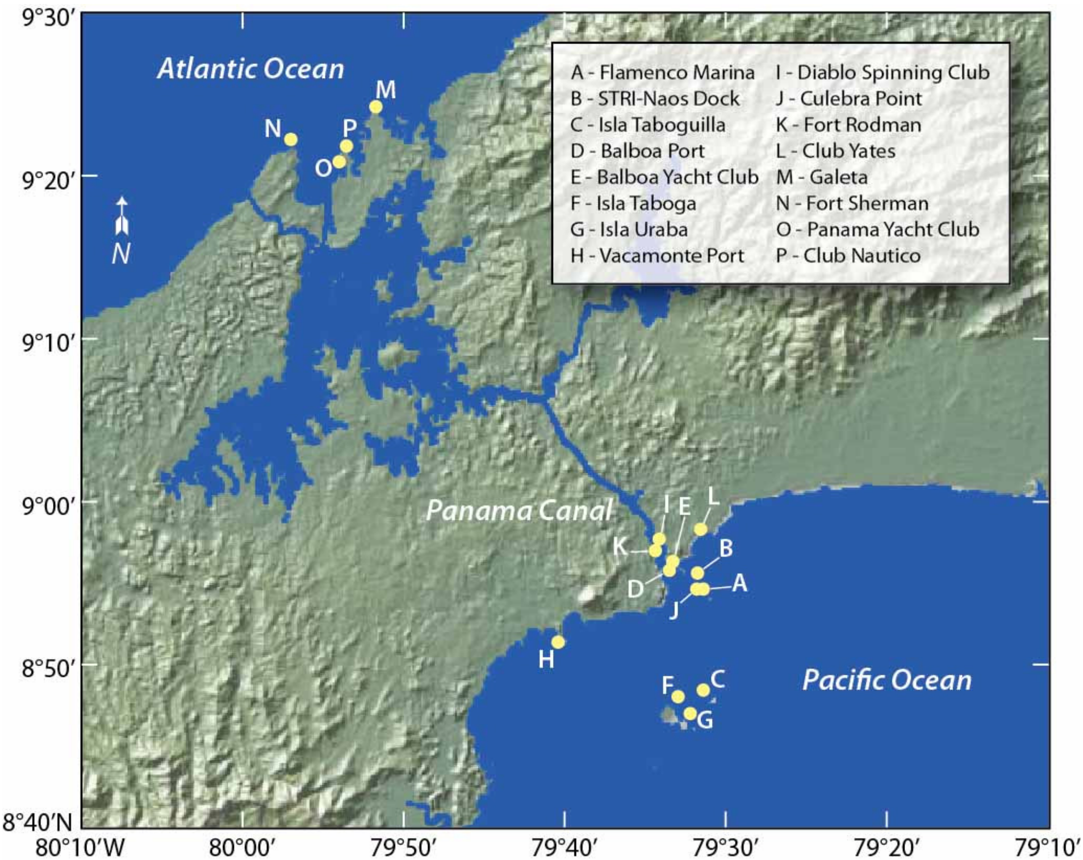

Figure 1. Map of the study area with surveyed sites indicated (for details see Appendix 1).

Pacific surveys (Appendices 1–2). This is the first report of *Polyandrocarpa anguinea* (Sluiter, 1898) and *P. sagamiensis* Tokioka, 1953 in Atlantic Panama waters and *Ascidia incrassata* Heller, 1878, *Ascidia sydneiensis* Stimpson, 1855, *Botrylloides nigrum* Herdman, 1886, *Botryllus planus* (Van Name, 1902), *Didemnum perlucidum* Monniot, 1983, *Diplosoma listerianum* (Milne-Edwards, 1841), *Microcosmus exasperatus* Heller, 1878, *Polyandrocarpa zorritensis* (Van Name, 1931), *Polyclinum constellatum* Savigny, 1816, *Symplegma brakenhielmi* Michaelsen, 1904, *Symplegma rubra* Monniot, 1972, and *Trididemnum orbiculatum* (Van Name, 1902) in Pacific Panama waters.

Both Pacific and Atlantic ascidian faunas at the Panama Canal were dominated by non-native or cryptogenic species. Non-native species were very abundant; native species were less common or rare (Table 2). Six species occurred on both sides of the canal [*A. sydneiensis, B. nigrum, D. listerianum, M. exasperatus, P. constellatum,* and *Styela canopus* (Savigny, 1816)]; all are species common to the fouling communities of ports and marinas of the world. We considered the new species, *Ascidia* sp., as a native species (Table 2) because we found it in Panama waters but it may be a cryptogenic or introduced species.

Discussion

The ascidian fauna at the Atlantic and Pacific sides of the Panama Canal are very diverse compared to other areas that have been surveyed. We found approximately 20 species of ascidians

Table 1. Ascidian species previously documented in Pacific waters of Panama and Costa Rica. x=present. Author codes: 1. Van Name (1945), 2. Tokioka (1971), 3. Tokioka (1972), 4. Menge et al. (1983), 5. Monniot (1994), 6. Cohen (2006).

Species	Panama	Costa Rica	Authors
Aplidium constellatum (Verrill, 1871)		x	3
Ascidia ceratodes (Huntsman, 1912)		x	3
Botryllocarpa viridis (Pizon, 1908)[1]		x	3
Botryllus schlosseri (Pallas, 1766)	x		6
Chelyosoma inaequale Redikorzev, 1913	x		1
Cnemidocarpa drygalskii (Hartmeyer, 1911)	x		1
Didemnum candidum Savigny, 1813[2]		x	3
Didemnum carnulentum Ritter and Forsyth, 1917	x		1
Didemnum moseleyi (Herdman, 1886)		x	3
Didemnum vanderhorsti Van Name, 1924	x		1
Eudistoma pachecae Van Name, 1945	x		1,4
Eusynstyela sp. cf. *tincta* (Van Name, 1902)		x	3
Lissoclinum caulleryi (Ritter and Forsyth, 1917)		x	3
Lissoclinum fragile (Van Name, 1902)		x	3
Polyclinum laxum Van Name, 1945		x	3
Pyura lignosa Michaelsen, 1908	x	x	3,5
Pyura vittata (Stimpson, 1852)	x		4
Pyura sp. cf. *vittata*		x	3
Rhopalaea birkelandi Tokioka, 1971		x	2, 3
Styela milleri Ritter, 1907	x		1
Styela canopus (Savigny, 1816)	x	x	1,3
Trididemnum opacum (Ritter, 1907)	x		1

[1] as *Symplegma pizoni* in Tokioka (1972), but see Kott (1990) for further discussion.
[2]*D. candidum* is probably an incorrect identification. For many years many white didemnids were identified as *D. candidum* because researchers did not recognize the significance of differences in the larvae, spicules, tunic and other morphological characters.

on each side of the Panama Canal, while Pederson et al. (2005) found 13 species in one RAS along 300 miles of Atlantic coast from Maine to New York City and Cohen et al. (2005) found 26 along 250 miles of Pacific coast in southern California. Cohen (2006) found six ascidian species on the Pacific side of the Panama Canal and 16 ascidian species on the Atlantic side of the canal, but the length of coastline surveyed is unknown. Of the Pacific Panama species observed, only *Ascidia ceratodes* (Huntsman, 1912), *Lissoclinum fragile* (Van Name, 1902), *Pyura lignosa* Michaelsen, 1908, *Rhopalaea birkelandi* Tokioka, 1971, and *S. canopus* have been previously reported in Pacific Panama or Costa Rica waters. Of the Atlantic Panama species observed, all but the two *Polyandrocarpa* species have been previously reported in Atlantic Panama or Caribbean waters (Table 2).

We found more non-native species in the Pacific ascidian fauna (7 species, 35%) than the Atlantic ascidian fauna (2 species, 10%). By comparison, there were seven species (54%) in New England (Pederson et al. 2005) and 14 (54%) in southern California (Cohen et al. 2005). Our figures are conservative because of the high number of species designated as cryptogenic; some if not all of these cryptogenic species may be non-native which would bring the number of Atlantic Panama non-natives to 14 (70%) and Pacific Panama non-natives to 12 (60%). Lambert and Lambert (2003) showed that there is a significant latitudinal increase in non-native ascidian species in estuaries on the Pacific coast from Alaska to southern California.

Ascidian diversity may be related to coastal development patterns and environmental impacts (Carman et al. 2007). Ascidians are common inhabitants of harbors and marinas in temperate

Table 2. Ascidian species at the Panama Canal, status and geographic distribution.Abbreviations: C=Cryptogenic; I=Introduced; N=Native.

Species	Pacific	Atlantic	Status	Known distribution	Probable geographical origin	Source
Ascidia ceratodes	x		N	California, USA (Pacific) to N Chile	E Pacific	Van Name (1945), Tokioka (1972), Lambert and Lambert (1998, 2003)
Ascidia curvata		x	N	Bermuda, USA (Florida), Caribbean, Brazil	Tropical W Atlantic	Van Name (1945), Rocha and Kremer (2005)
Ascidia incrassata	x		I	South Africa, Mozambique	SW Indian Ocean	Monniot et al. (2001)
Ascidia interrupta		x	N	Bermuda, USA (North Carolina and Florida), Caribbean, Brazil, Azores, Gulf of Mexico	Tropical W Atlantic	Van Name (1945), Monniot (1983), Monniot and Monniot (1994), Rocha et al. (2005), Lambert et al. (2005)
Ascidia sydneiensis	x	x	I	Caribbean, SE and S Brazil, tropical E Atlantic, South Africa, Philippines, W Pacific, Hawaii, Guam, Palau, Polynesia	W Pacific	Van Name (1945), Kott and Goodbody (1982), Monniot (1983, 1987, 1997), Monniot and Monniot (1987), Abbott et al. (1997), Lambert (2002), Rocha and Kremer (2005)
Ascidia sp.	x		N	Panama (Pacific)	Panama (Pacific)	Bonnet and Rocha unpubl. data
Ascidia panamensis		x	N	Panama (Atlantic)	Panama (Atlantic)	Bonnet and Rocha (2011)
Botrylloides nigrum	x	x	C	Caribbean, Brazil, W and E Africa, Australia, Guam, China, Japan	W Atlantic? W Pacific?	Lambert (2003), Rocha and Kremer (2005), Rocha and Bonnet (2009)
Botrylloides sp.	x					
Botryllus planus	x		I	Bermuda, USA (Florida), Caribbean, Brazil	W Atlantic	Rocha and Kremer (2005), Rocha and Bonnet (2009)
Didemnum psammathodes		x	C	Caribbean, Gulf of Mexico, SE Brazil, E Africa, South Africa, Red Sea, Philippines, tropical W Pacific, Hawaii, Guam	?	Eldredge (1967), Tokioka (1970), Monniot (1983, 1995), Goodbody (1984), C Monniot and F Monniot (1994), F Monniot and C Monniot (1996, 1997, 2001), Rocha and Monniot (1995), Kott (1998), Monniot et al. (2001), Lambert (2002, 2003), Lambert et al. (2005)
Didemnum perlucidum	x		I	Caribbean, S and SE Brazil, Senegal, Indo-west Pacific, Zanzibar, Hawaii, Guam, Palau, Florida, Gulf of Mexico	?	Monniot (1983), Rocha and Monniot (1995), Monniot and Monniot (1996), Godwin and Lambert (2000), Paulay et al. (2002), Lambert (2003)
Didemnum sp. white with green algae		x				
Didemnum sp.	x					
Diplosoma listerianum	x	x	C	Wide spread in tropical and temperate waters of all oceans	?	Lambert and Lambert (1998), Lambert (2002), Rocha and Kremer (2005), Rocha and Bonnet (2009)
Herdmania pallida		x	C	USA (Florida) to SE Brazil, Cape Verde, Gabon, South Africa, W Indian Ocean, Indo-west Pacific, Australia, Hawaii, Guam	Indo-west Pacific?	Kott (2002), Monniot (2002), Lambert (2003)
Lissoclinum fragile	x		I	Bermuda, Caribbean, Brazil, Argentina, Azores, Sierra Leone, Arabic Gulf, S Australia, W Pacific, Hawaii, Guam	?	Van Name (1945), Lambert (2003), Rocha and Kremer (2005), Rocha and Bonnet (2009)
Lissoclinum verrilli		x	N	Caribbean, New Caledonia, Brazil, Panama	Carribean	Van Name (1945), Rocha et al. (2005), Monniot (2007)

Table 2 (continued).

Species	Pacific	Atlantic	Status	Known distribution	Probable geographical origin	Source
Microcosmus exasperatus	x	x	C	Bermuda, Caribbean, SE USA, Brazil, Mediterranean, South Africa, W Africa, Australia, W Pacific, Hawaii, Guam	?	Van Name (1945), Lambert (2002, 2003), Rocha and Kremer (2005)
Perophora viridis		x	N	Bermuda, Atlantic USA, Caribbean, Brazil, Azores, Sierra Leone, New Caledonia, Easter Island	W Atlantic	Van Name (1945), Millar (1957), Monniot (1974), Goodbody (1994), Rocha and Bonnet (2009)
Phallusia nigra		x	C	Bermuda, USA (Florida), Caribbean, Brazil, Guinea, Angola, Mediterranean, Red Sea, Persian Gulf, Indo-west Pacific, Hawaii, Guam	W Atlantic? Persian Gulf?	Van Name (1945), Millar (1958, 1975), Pérès (1958), Abbott et al. (1997), Lambert (2003)
Polyandrocarpa anguinea		x	C	SE USA (Florida), Panama, Martinica, SE Brazil, Sierra Leone, South Africa, Mauricius Island, Indonesia, Phillipines, Australia, New Caledonia	?	Van Name (1918), Millar (1955, 1962), Rodrigues (1977), Monniot and Monniot (1994)
Polyandrocarpa sagamiensis		x	I	Japan, Guam, Hawaii	W Pacific	Tokioka (1953), Abbott et al. (1997), Lambert (2003)
Polyandrocarpa zorritensis	x		C	SW USA (California), Peru, S and SE Brazil, Mediterranean, Japan, Hawaii	?	Van Name (1945), Nishikawa et al. (1993), Abbott et al. (1997), Lambert and Lambert (1998, 2003), Rocha and Kremer (2005)
Polyclinum constellatum	x	x	C	Bermuda, USA (Florida, Gulf of Mexico) to S Brazil, South Africa, W Indian Ocean, W Pacific, Hawaii, S California	?	Van Name (1945), Tokioka (1967), Millar (1975), C Monniot and F Monniot (1987), F Monniot and C Monniot (1997, 2001), Monniot (1987), Abbott et al. (1997), Lambert (2002)
Pyura lignosa	x		N	Caribbean, Costa Rica, Panama (Pacific), Gulf of California, S California, Majuro, Japan, Philippines	Pacific coast Central America	Van Name (1945), Tokioka (1970), C Monniot (1983, 1994), Nishikawa (1984)
Pyura torpida		x	N	Cuba, Guadalupe, Panama, Colombia	Caribbean	Van Name (1945), C Monniot (1983), Rocha et al (2005)
Pyura vittata		x	C	Bermuda, USA (North Carolina and Florida), Caribbean, Brazil, E and W Africa, India, Hong Kong, Indonesia, Palau	W Pacific?	Van Name (1945), Abdul and Sivakumar (2007), Monniot (2009), Rocha and Bonnet (2009)
Rhopalaea birkelandi	x		N	Costa Rica and Panama (Pacific coast)	Pacific coast Central America	Tokioka (1971, 1972)
Styela canopus	x	x	C	E and W Atlantic, Indian Ocean, Australia, W Pacific, Hawaii, Guam, Easter Island, USA (California)	Pacific?	Kott (1985), Lambert and Lambert (1998, 2003), Lambert (2003), Rocha and Bonnet (2009)
Symplegma brakenhielmi	x		C	Caribbean, Brazil, Indian Ocean, W Pacific, Hawaii	?	C Monniot (1983), Kott (1985), C Monniot and F Monniot (1987, 1997), F Monniot and C Monniot (2001), Abbott et al. (1997), Lambert (2002)
Symplegma rubra	x		I	Bermuda, Caribbean, Gulf of Mexico, S and SE Brazil, E Africa, Palau	Caribbean?	F Monniot and C Monniot (1997), Lambert et al. (2005), Rocha and Kremer (2005)
Tridideumnum orbiculatum	x		I	Bermuda, USA (Florida), Caribbean, Brazil	W Atlantic	Van Name (1945), F Monniot (1983), Rocha and Bonnet (2009)

and tropical waters (Van Name 1945; Monniot et al. 1991). In particular, because of their ability to be transported by ships and boats, ascidian diversity may be correlated with coastal shipping patterns, especially of non-native species. Thus, the high diversity of ascidians, especially introduced, non-native species, that we found was expected.

It is unclear whether ships introduced the non-native ascidians we found to the Panama Canal area and what role the canal serves as a corridor for these species. The canal is comprised of a series of interconnected freshwater lakes and this barrier probably inhibits some ascidian transfers. However, many ships take only about 11 h to transit the canal and some ascidian species are known to survive long periods with closed siphons (Sims 1984; Katayama and Ikeda 1987; A Coutts unpubl. obs.). In addition, ships are often required to wait several days at the entrance to the canal before they can transit. As a result, ships originating throughout the Pacific and Atlantic cluster together at mooring and anchor sites near the mouths of the canal. These ships could serve as major vectors for intra-oceanic introductions.

Environmental conditions can influence ascidian populations (Lambert 2001, 2005). Rainy season inputs to the study area can be considerable (Ibáñez 2005) but rainfall only temporarily reduces inshore salinity, particularly where tidal fluxes are large. *Ascidia* spp. and *R. birkelandi* must be able to tolerate a wider range of salinity and sediment fluxes than other ascidian species observed in our surveys because we easily found them in waters with salinity measurements of 29 to 36 psu and in shallow waters immediately adjacent to terrestrial sediment sources. High concentrations of nutrients usually coincide with heavy rainfall as well as coastal development; dissolved inorganic nutrients and plankton are at high concentrations in Panama coastal environments (D'Croz et al. 2005). Shallow water ascidians benefit from coastal nutrient input; this may be the reason for high ascidian biomass in Panamanian harbors and marinas on both the Atlantic and Pacific coasts. However, high levels of sediment flushed into systems by rainfall may negatively affect ascidians (Whitlatch and Osman 2000; Petersen 2007).

The ascidian faunas at both entrances to the Panama Canal are probably constantly changing because of frequent species introductions, disturbances due to coastal development, and seasonal changes in environmental parameters (e.g., rainfall). Two of our sites were surveyed in 2002 (June, beginning of rainy season) and again in December 2008/January 2009 (end of rainy season). We treated the 2002 and 2008/2009 surveys as time-inclusive, though there were changes in the ascidian faunal composition at the two sites that were surveyed in both 2002 and 2008/2009. At the Balboa Yacht Club, three non-native species were recorded in 2002 and only one species (a different non-native species) was observed in 2008/2009. At the dock of the Smithsonian Tropical Research Institute (STRI)-Naos, four species (non-native) were recorded in 2002 and eight species (7 non-native and 1 native) were observed in 2008/2009 (Appendix 2). Increasing anthropogenic development along the Panama coastline may contribute to a change in the ascidian population, as increasing coastal development is associated with the increased presence of non-native species in temperate Pacific waters (Wonham and Carlton 2005). Cohen (2006) documented other non-native taxa at the Panama Canal, including barnacles, sponges, bryozoans, crabs, and fish. The construction of a third lane at the Panama Canal (2008–2014) is expected to double the number of ships going through the canal (Canal de Panamá 2010). To determine how Panamanian ascidian communities change over time, comprehensive baseline data should be collected annually at the same time of year.

Acknowledgements

We thank Javier Jara and Mark Torchin, STRI-Naos Lab, for lab and field logistics, Zachary Carman for field assistance, and James Carlton and an anonymous reviewer. Funding for this project came from WHOI Ocean Life Institute-Tropical Research Initiative to Carman and CNPq to Rocha. The Pew Tropical Invasions Project #2002 to Andrew Cohen provided funding to Lambert.

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Supplementary material

The following supplementary material is available for this article.

This material is available as part of online article from:
http://www.aquaticinvasions.net/2011/AI_2011_6_4_Carman_etal_Supplement.pdf

Appendix 1. Surveyed sites at Pacific and Atlantic entrances to the Panama Canal in 2002, 2008, 2009.

Appendix 2. Ascidian species on natural and artificial substrates at Pacific and Atlantic entrances to the Panama Canal 2002, 2008, 2009.