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Editorial

Trends in invasive ascidian research: a view from the 3rd International Invasive Sea Squirt Conference

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The 1st International Invasive Sea Squirt Conference was organized in 2005 in response to a growing awareness of the economic and ecological effects of a recent wave of invasions of ascidians, also known as sea squirts or tunicates (Whitlatch and Bullard 2007). The intent was to provide opportunities for researchers and coastal managers to identify research and management needs, and to generate ideas for future study. Common themes rapidly emerged in the information shared by conference participants, who represented nine countries, and underlined the worldwide nature of the problem. For example, the accelerating pace of invasions by tunicates, the frequent dominance of fouling communities on artificial and/or floating structures such as aquaculture facilities and recreational docks, and the potential for tunicates to become pests in an invaded environment were observations that were repeated across a variety of world regions, ecosystems, and taxa (Locke and Carman 2009).

By the time the second conference was held in 2007, it was apparent that many of the same species of tunicates showed up repeatedly as members of the worldwide invader fauna, particularly in temperate regions (Locke and Carman 2009). The severity of impacts varied among regions, but the environmental reasons why this might be so, and the need for development of methodologies for management and mitigation of impacts, were highlighted as issues requiring further investigation (Locke and Carman 2009). As a follow-up, a third conference was held in April 2010.

With three conferences completed (Whitlatch and Bullard 2007; Locke and Carman 2009; this issue), comprising 150 abstracts, it seemed timely to examine the abstracts for trends in invasive tunicate research. Specifically, we wished to determine which locations, species, and major themes were investigated, and whether these changed over time.

Abstracts for the three conferences are maintained online by Woods Hole Oceanographic Institution at http://www.whoi.edu/page.do?pid=11421, http://www.whoi.edu/page.do?pid=17276, and http://www.whoi.edu/page.do?pid=33341, respectively. For each abstract, we listed the species studied, the location of the study (laboratory studies were omitted from this step unless conducted with field-collected tunicates), and the main topics of the study. Species coverage was classed as 'community' where more than four species were investigated in a single study (or if the entire tunicate fauna was surveyed); and all tunicate species were treated equally, regardless of their status (i.e., invasive, cryptogenic, or native) in the study area.

Reflecting the location of the conferences, all of which have been held in eastern North America, > 60% of the papers presented each year described studies conducted on the Atlantic coasts of North and Central America, north of the equator (NW Atlantic, Table 1). The majority of these abstracts were derived from studies in the USA and Canada, with a few from the Atlantic coast of Panama. The Northeastern Pacific, comprising the Pacific coasts of Canada, USA, Mexico and Panama, was the second most commonly represented region, accounting for 6–17% of the abstracts. World-wide studies were represented in 8–13% of abstracts, and Northeastern Atlantic (mainly papers from The Netherlands and the UK) an additional 2–10%. Papers on the Southwestern Pacific (New Zealand, Australia), and Southwestern Atlantic (Brazil) were presented at all three conferences. The Mediterranean and Red Seas, Southeastern Atlantic, and Northern and Southern Indian Oceans were each represented at one conference.

In 2005, 44% of the abstracts that could be classified addressed tunicates at the whole-community level (Table 2). In 2007 and 2010, this percentage declined to ≤ 26%, suggesting that studies were focusing on specific taxa – most likely recent invaders or those considered to have the most negative effects. While 16 genera were studied, five genera (*Styela*, *Botrylloides*, *Didemnum*, *Botryllus*, and *Ciona*) received the most attention with the most commonly studied species being *Didemnum vexillum*, *Botrylloides violaceus*, *Botryllus schlosseri*, *Styela clava*, and *Ciona intestinalis*. In part, this reflected the most common problem-species in the Northwestern Atlantic Ocean, which was the region that dominated in terms of numbers of abstracts submitted. However, these five species were each studied in at least one other region, including: the Northeastern and Southwestern Pacific; Northeastern and Southeastern Atlantic Oceans; and Mediterranean Sea.

Ecological interactions were the dominant topic (32%) of the first conference (Table 3), declining to 12% by 2010. Studies of the use of habitat by tunicates similarly declined as the emphasis shifted to more applied work. Somewhat surprisingly, studies of the impacts of tunicates on ecosystems outnumbered those of the impacts of tunicates on aquaculture at all three conferences. Surveys of tunicate abundance and distributions remained important throughout the three conferences. Development of, and comparisons between, monitoring methods increased from 5% to 20% of submissions over the three conferences. While treatments for tunicates were already being tested or used in 2005 (8% of papers), they were emphasized more in 2007 and 2010, and formal plans for the management of tunicates were presented in the 2nd and 3rd conferences.

A few new records of species occurrences were presented in every conference (Table 3). Taxonomic work to clarify the identity of worldwide *Didemnum vexillum* populations was

Table 1. Locations (as % of studies) included in 139 studies presented at International Invasive Sea Squirt Conferences in 2005, 2007 and 2010.

Location of study	2005	2007	2010
World	8	13	6
NE Atlantic Ocean	8	2	10
Mediterranean Sea	0	5	0
Red Sea	0	2	0
NW Atlantic Ocean	67	60	69
SE Atlantic Ocean	0	2	0
SW Atlantic Ocean	3	2	4
NE Pacific Ocean	17	9	6
SW Pacific Ocean	3	9	8
N Indian Ocean	3	0	0
S Indian Ocean	0	2	0
Number of studies included	36	55	48

Table 2. Taxa (as % of studies) included in 140 studies presented at International Invasive Sea Squirt Conferences in 2005, 2007 and 2010.

Taxon or unit of study	2005	2007	2010
Community	44	26	24
Ascidiella aspersa (Müller, 1776)	0	0	4
Botrylloides violaceus Oka, 1927	22	11	22
Botryllus schlosseri (Pallas, 1766)	11	7	24
Ciona intestinalis (Linnaeus, 1767)	6	13	20
Clavelina lepadiformis (Müller, 1776)	0	0	2
Clavelina oblonga Herdman, 1880	3	0	0
Corella eumyota Traustedt, 1882	3	0	0
Didemnum perlucidum F. Monniot, 1983	0	0	2
Didemnum vexillum Kott, 2002	17	26	28
Diplosoma listerianum (Milne-Edwards, 1841)	6	0	0
Distaplia occidentalis Bancroft, 1899	0	0	2
Eudistoma elongatum (Herdman, 1886)	0	0	2
Herdmania momus (Savigny, 1816)	0	2	0
Microcosmus squamiger Michaelsen, 1927	6	4	0
Molgula manhattensis (De Kay, 1843)	3	0	0
Perophora japonica Oka, 1927	6	0	2
Polyclinum constellatum Savigny, 1816	0	0	2
Styela clava Herdman, 1881	22	28	8
Styela plicata (Lesueur, 1823)	0	4	2
Styela (genus) Fleming, 1822	0	0	2
Number of studies included	36	54	50

highlighted in the second conference with one paper using traditional taxonomic methods and a second paper utilizing molecular analyses. Molecular analyses of tunicates were represented in all three conferences, initially to identify source populations or in a research context to understand genetic variability or distribution on a worldwide scale. By the second conference, the emphasis of molecular techniques was shifting to the development of detection techniques, for example to assay water samples for the presence of tunicate genetic material.

There has been relatively little empirical work presented on the patterns of local establishment and spread, or on the biogeography of tunicates. However, predictions and future trends for tunicate distribution were the subjects of papers starting in the 2nd conference along with mathematical models examining local dispersal and establishment (Table 3). Predictions related to temperature tolerances and expected climate change effects on distributions were included at all three conferences. Somewhat surprisingly, few papers specifically addressed the issue of vectors, likely because this is difficult to determine with certainty. Lastly, a few papers addressed the question of potential commercial uses of tunicates or their epibionts.

This special edition of *Aquatic Invasions* includes 17 papers presented during the 3rd International Invasive Sea Squirt Conference, held in Woods Hole, MA, USA on 26–28 April 2010. The first group of papers present the results of surveys conducted in North and Central America. Two of these deal with the ascidian biota of Panama (Carman et al. 2011, Bullard et al. 2011). The results of multi-year monitoring programs in Atlantic Canada are presented for Nova Scotia (Sephton et al. 2011) and the Bay of Fundy (Martin et al. 2011) while McNaught and Norden (2011) summarize survey results in the adjacent waters of the state of Maine. The next group of papers addresses ascidian fouling in coastal waters of the Netherlands, including the use of artificial structures (Gittenberger and van Stelt 2011), a study of seasonal succession (Lindeyer and Gittenberger 2011), and examination of the spatial interactions between *Botryllus schlosseri* and *Botrylloides violaceus* (Gittenberger and Moons 2011). The role of *Didemnum perlucidum* as a competitor in a fouling community in Brazil is studied by Kremer and Rocha (2011). Dijkstra and Nolan (2011) present an experiment to determine the impacts of *Didemnum vexillum* overgrowth on the swimming capacity of the sea scallop *Placopecten magellanicus* (Gmelin, 1791). Culture techniques to produce *Didemnum vexillum* on demand for laboratory experiments are described by Fletcher and Forrest (2011). More common, however, is research on methods to kill tunicates or at least control their abundance, generally intended for use on bivalve aquaculture structures. Papers in this area include the use of pressurized seawater for the treatment of colonial tunicates (Arens et al. 2011a), and the potential for this treatment to affect cultured bivalves (Arens et al. 2011b). Willis and Woods (2011) test a larval inhibitor for *Styela clava*, and Page et al. (2011) present trials of a variety of methods to control *Eudistoma elongatum*. The remaining papers in the special issue are also related to the management and control of tunicates. Vercaemer et al. (2011) examine the effects of environmental conditions on the life history processes of *Ciona intestinalis*, with management implications such as the selection

Table 3. Main themes (as % of papers) addressed by 150 papers presented at International Invasive Sea Squirt Conferences 2005, 2007 and 2010.

Topic	2005	2007	2010
Ecological interactions	32	18	12
Survey results	27	23	27
Impacts on ecosystem or components	19	16	10
Temperature / climate change prediction	19	13	14
Use of habitat	19	8	6
Genetics	8	16	10
Management methods (treatments)	8	15	14
Patterns of establishment and spread	8	2	0
Monitoring methods development	5	10	20
Biogeography	5	3	6
Vectors	3	11	4
Impacts on aquaculture	3	5	0
New records of species	3	3	6
Industrial / medical uses of tunicates or epibionts	3	4	0
Management (plans)	0	10	4
Predictions / future trends	0	3	2
*Taxonomy (traditional)	0	3	0
Mathematical models	0	2	4
Culture techniques	0	2	2
Number of studies	37	62	51

of aquaculture sites that are poor habitat for fouling species of tunicates. Finally, Kanary et al. (2011) model the larval dispersal of *Ciona intestinalis*, in order to determine and potentially interrupt the likely routes of dispersal from a known point of entry to an aquaculture site.

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