Rapid Communication

2019 Rapid Assessment Survey of marine bioinvasions of southern New England and New York, USA, with an overview of new records and range expansions

Judith Pederson[1,*], James T. Carlton[2], Carolina Bastidas[1], Andrew David[3], Sara Grady[4], Lindsay Green-Gavrielidis[5], Niels-Viggo Hobbs[6], Cristina Kennedy[7], Jennifer Knack[3], Megan McCuller[8], Brandon O'Brien[9], Kristin Osborne[10], Sabrina Pankey[9] and Thomas Trott[11]

[1]*MIT Sea Grant College Program, Cambridge, Massachusetts, USA*
[2]*William College-Mystic Seaport Maritime Studies Program, Mystic, Connecticut, USA*
[3]*Clarkson University, Potsdam, New York, USA*
[4]*North-South River Watershed Association, Marshfield, Massachusetts, USA*
[5]*Salve Regina University, Newport, Rhode Island, USA*
[6]*Connecticut College, New London, Connecticut, USA*
[7]*Massachusetts Office of Coastal Zone Management, Boston, Massachusetts, USA*
[8]*North Carolina Natural Sciences Museum, Raleigh, North Carolina, USA*
[9]*University of New Hampshire, Durham, New Hampshire, USA*
[10]*Massachusetts Maritime Academy, Buzzards Bay, Massachusetts, USA*
[11]*Maine Coastal Program, Department of Marine Resources, West Boothbay Harbor, Maine, USA*

Author e-mails: *jpederso@mit.edu (JP), james.t.carlton@williams.edu (JTC), bastidas@mit.edu (CB), adavid@clarkson.edu (AD), sara@nsrwa.org (SG), l.greengavrielidis@salve.edu (LG-G), hamavos.niels@gmail.com (N-VH), cristina.kennedy@mass.gov (CK), jknack@clarkson.edu (JK), megan.mcculler@naturalsciences.org (MMC), bso1002@wildcats.unh.edu (BOB), kosborne@maritime.edu (KO), sabrina.pankey@unh.edu (SP), tom.trott@maine.gov (TT)*

**Corresponding author*

Citation: Pederson J, Carlton JT, Bastidas C, David A, Grady S, Green-Gavrielidis L, Hobbs N-V, Kennedy C, Knack J, McCuller M, O'Brien B, Osborne K, Pankey S, Trott T (2021) 2019 Rapid Assessment Survey of marine bioinvasions of southern New England and New York, USA, with an overview of new records and range expansions. *BioInvasions Records* 10(2): 227–237, https://doi.org/10.3391/bir.2021.10.2.01

Received: 16 September 2020
Accepted: 1 December 2020
Published: 11 February 2021

Handling editor: Mary Carman
Thematic editor: April Blakeslee

Abstract

A marine bioinvasions Rapid Assessment Survey in August 2019, focused on marina floating pontoons in Rhode Island, Connecticut and New York recorded 21 non-indigenous, 22 cryptogenic and 2 range-expanding species. Five non-indigenous species (NIS) were found at more than 70% of the 10 sampled sites: three ascidians, *Botryllus schlosseri* (Pallas, 1766) (a probable mixture of introduced and native populations), *Botrylloides violaceus* Oka, 1927, and *Styela clava* Herdman, 1881; a crab, *Hemigrapsus sanguineus* (de Haan, 1835), and a sea anemone, *Diadumene lineata* (Verrill, 1869). The sea anemone *Aiptasiogeton eruptaurantia* (Field, 1949), native to the southern United States, is newly reported from New York. The southern U.S. barnacle *Amphibalanus subalbidus* (Henry, 1973) was detected for the first time in Connecticut in Long Island Sound. It had been six years since the last rapid assessment survey of marinas in Rhode Island and 16 years for marinas in Connecticut and New York. During this six to 16 year hiatus, we found northern range expansions, expansion of recent invaders and generally consistent presence of previous NIS at high levels of occurrence.

Key words: introduced species, fouling communities, poleward movement

Introduction

Along with climate change and habitat loss, species introductions have a major impact on biodiversity and ecosystem services (Bax et al. 2003; Simberloff et al. 2013). Regularly repeated biodiversity surveys supported by accurate taxonomy are fundamental to detecting new invasions, documenting changing distributions of prior invaders, understanding impacts and community responses to climate change, and for making management and policy decisions (Pederson et al. 2005; Mathieson et al. 2008; Pyšek et al. 2013; McIntyre et al. 2013; Marchini et al. 2015).

Over the past several decades, researchers have increasingly focused on understanding the diversity and distribution of non-indigenous species (NIS) in coastal and marine habitats. A variety of approaches are used for this work, including sampling biofouling communities on marina and harbor docks, floats, and pontoons, as well as deploying experimental settlement plate arrays in the same habitat. Diving and photographic surveys may supplement these approaches, as do studies in additional habitats, such as rocky shorelines, intertidal sand-mud flats, eelgrass beds, and salt marshes (Pederson et al. 2005; Grey 2009; Dijkstra et al. 2007; Dijkstra and Harris 2009; Collin et al. 2015; Nall et al. 2015; Trott and Enterline 2019). Surveys may also target specific taxonomic groups, such as ascidians (Brunetti and Cuomo 2014; Tracy et al. 2017; Villalobos et al. 2017; Ma et al. 2017). All of these efforts require the availability of extensive and broad taxonomic expertise, increasingly complemented by molecular genetic analyses (for example, David and Krick 2019).

Rapid Assessment Surveys (RAS) focused on documenting marine NIS have been conducted in the New England – New York region of the United States since 2000, with the first six surveys being held every three to five years (Pederson et al. 2005; Mathieson et al. 2008; McIntyre et al. 2013; Wells et al. 2014; Kennedy et al. 2020). Even at these intervals, each RAS has detected new invasions or new range expansions. These RAS, which have attempted to assess a broad suite of invertebrate and algal taxa, have focused primarily on biofouling communities on floating pontoons in marinas and harbors, providing long-term consistency in sampling a uniform habitat accessible regardless of tidal cycles. The majority of sampling stations have been and continue to be subject to human-mediated dispersal vectors, including commercial and recreational vessel traffic and aquaculture activities.

However, as of 2019, the southern New England region had not been the subject of a RAS for 6 years in Rhode Island and for 16 years in Connecticut and New York. In order to address these temporal sampling gaps, a RAS survey was conducted in August 2019 from Rhode Island to New York.

Materials and methods

Ten stations in southern New England and New York were surveyed for invertebrate and algal species in marine fouling communities from August 17–20, 2019 (Table 1, Figure 1). Of the ten RAS 2019 sites, six were visited in previous surveys from one to three times, and one was in close proximity to a previous site that had recently closed. Of the ten locations, three were in

Table 1. RAS August 2019 marina locations in Southern New England and New York. One asterisk indicates locations visited in previous surveys, and two asterisks close proximity to a previous location.

Site Code	Location	State and City RI: Rhode Island, CT: Connecticut, NY: New York	Longitude	Latitude
STB	Save the Bay docks**	Providence, RI	–71.3813	41.7856
ALH	Allen Harbor Marina*	North Kingstown, RI	–71.4113	41.6213
PTJ	Point Judith Marina*	Wakefield, RI	–71.5172	41.3877
BMM	Brewer Mystic Marina*	Mystic, CT	–71.9680	41.3467
SBJ	Bruce and Johnsons Marina	Branford, CT	–72.8030	41.2654
CED	Cedar Marina	Bridgeport, CT	–72.2106	41.1589
SHS	Stirling Harbor Shipyard*	Greenport, NY (Long Island)	–72.3581	41.1123
BYH	Brewer Yacht Haven Marina*	Stamford, CT	–73.5345	41.0329
MBG	Moonbeam Gateway Marina	Brooklyn, NY	–73.8994	40.5881
GKS	Great Kills Marina*	Great Kills (Staten Island) NY	–74.1330	40.5364

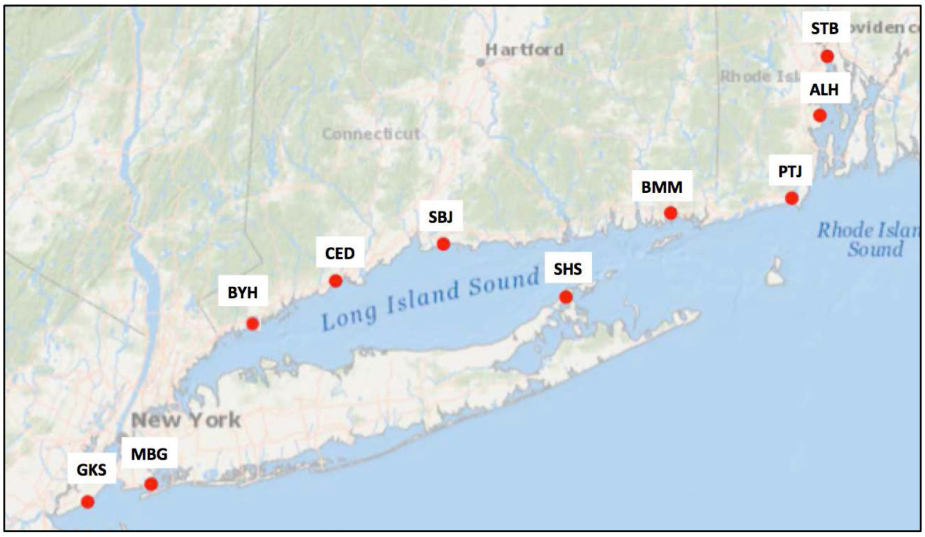

Figure 1. Map of southern New England New York RAS 2019 stations (see Table 1).

Rhode Island, four in Connecticut and three in New York (Figure 1; Table 1). Physical-chemical data collected included temperature, salinity, dissolved oxygen, water transparency using a Secchi disk, and maximum depth.

The sampling protocol consists of deploying the survey team (typically 10–15 people) for 60 minutes at each site. Typically, three different locations are visited and sampled each day. At each station some team members are tasked with developing as detailed a species list as possible across all taxa, derived from field identifications by team members, collecting multi-species samples for laboratory analysis, and assembling a "community voucher", consisting of placing representatives of all common species as best as feasible in a liter jar (additional taxa may be added to the community voucher later in the laboratory). At the same time, taxonomists on the team concentrate on collecting specimens in their own specialties during the sampling period. Only floating pontoons and docks, attached ropes, tires, bumpers, buoys and other associated items were sampled. Fauna and flora on intertidal seawalls and pilings, or on private property (e.g., hulls of vessels) or found drifting on the water surface, are typically not included in the survey to ensure a uniform sampling method as noted

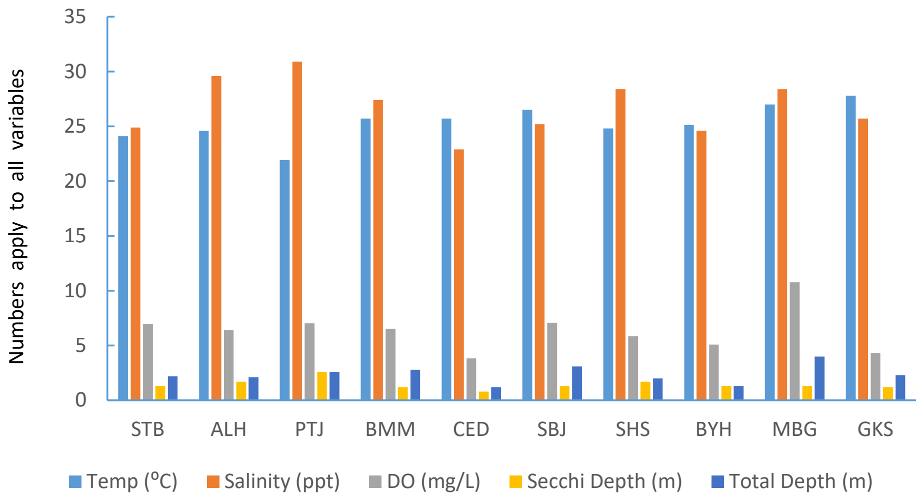

Figure 2. Sea surface temperature, salinity, dissolved oxygen (DO), Secchi depth, and total depth for each location from north to south.

above. Collections are made by hand, with scraping tools, or nets, and then labeled and placed in bags, jars, and vials with seawater and stored in coolers (ice chests) before continuing on to the next station.

At the end of each field day, samples are brought to a laboratory for verification of identifications and to identify species not resolved in the field. Processing extends from late afternoons to late evenings each day. Samples are then preserved in 95% ethanol. Individual specialists typically preserve samples for permanent archiving in their personal or institution collections and for further work-up at their home laboratories. Community vouchers are deposited at the Museum of Comparative Zoology of Harvard University, in Cambridge MA. For additional details of RAS field and laboratory methods, see Pederson et al. (2005).

Identified macroinvertebrates and algae are categorized as native, introduced, cryptogenic, or undetermined (Carlton 2009). The undetermined category includes taxa with insufficient taxonomic resolution to assign a probable biogeographic status. Not all taxa can be identified to species level; these may include juveniles or adults lacking reproductive structures or other identifying characters that can only be identified to genus, family, or at times a higher category. We define range expansion as species that are becoming established in regions in which they are not traditionally found and differentiate this movement from species that are seasonal in occurrence in New England or southern New York. Throughout this document, the Southern U.S. Atlantic is generally the region from Delaware and Chesapeake Bays to Florida.

Results

Environmental Data

Surface water environmental data for each station are shown in Figure 2. Sea surface temperatures generally increased slightly from north to south.

Salinity varied from a low of 22.9 psu at Cedar Marina, Bridgeport CT (CED) to a high of 30.9 ppt at Point Judith Marina, Wakefield RI (PTJ). Dissolved oxygen was lowest at CED (3.83 mg/L) and below 6 mg/L at both Great Kills Marina, Staten Island NY (GKS) and Brewer Yacht Haven Marina, Stamford CT (BYH). Secchi disc depth was between 0.8 m at CED and 2.6 m PTJ.

NIS Biodiversity, new NIS records and new distribution records

A total of 21 NIS, 22 cryptogenic and 2 range expansions were identified from Rhode Island to New York (Table 2; Supplementary material Tables S1, S2). Five NIS were found at more than 70% of the locations: three ascidians *Botryllus schlosseri* (Pallas, 1766) (a probable mixture of introduced and native populations; Yund et al. 2015), *Botrylloides violaceus* Oka, 1927, and *Styela clava* Herdman, 1881), the crab *Hemigrapsus sanguineus* (De Haan, 1835) and the sea anemone *Diadumene lineata* (Verrill, 1869). Non-native populations of *Botryllus schlosseri* are of European origin, while the other four NIS are from the Western North Pacific. One characteristic of abundant non-native species is their ability to often become spatially dominant. Examples of these in the 2019 RAS are the sea anemone *Diadumene lineata* (Figure 3A) and the bryozoan *Bugula neritina* (Linnaeus, 1758) (Figure 3B), both of which often presented nearly 100% estimated cover in waterline biofouling communities at sites indicated.

Several new records and new NIS distribution records were established (Table 3). The southern Atlantic U.S. barnacle *Amphibalanus subalbidus* (Henry, 1973) was newly found in Long Island Sound, and the southern Atlantic U.S. sea anemone *Aiptasiogeton eruptaurantia* (Field, 1949) was newly found in New York City. The Asian bryozoan *Tricellaria inopinata* d'Hondt and Occhipinti Ambrogi, 1985 was found on Long Island, establishing a new record for the state of New York, and its distribution was extended further west in Long Island Sound. New locations were established for the Asian amphipod *Grandidierella japonica* Stephensen, 1938.

Discussion

We conducted the last formal survey of marine biofouling communities of Block Island Sound west of Narragansett Bay and of Long Island Sound in August 2003 using our RAS protocol (Pederson et al. 2005). In the intervening 16 years, individual investigators have documented the presence and distribution of a number of new invasions in the region between Narragansett Bay and New York City. The shallow-water biofouling NIS that we documented represent approximately one-third of the roughly 70 non-indigenous marine species that are known to occur in the 275 km inland sea corridor from New York's Hudson River estuary to Buzzards Bay, Massachusetts across a wide variety of habitats, including float fouling, rocky

Table 2. Non-indigenous, cryptogenic, and range expanding species detected in the August 2019 Rapid Assessment Survey of southern New England and New York (distribution by station in Tables S1, S2). Status: NIS, non-indigenous species; C, cryptogenic species; RE, range expansions.

Taxon	Species	Status	Origin	Comments
Porifera (sponges)	*Halichondria bowerbanki* Burton, 1930	C	–	
	Haliclona canaliculata Hartman, 1958	C	–	
Cnidaria: Anthozoa (sea anemones)	*Diadumene lineata* (Verrill, 1869)	NIS	Northwest Pacific	
	Aiptasiomorpha eruptaurantia (Field, 1949)	RE	Southern U.S.	see Table 3
Cnidaria: Hydrozoa (hydroids)	*Obelia bidentata* Clark, 1875	C	–	
	Obelia dichotoma (Linnaeus, 1758)	C	–	
	Ectopleura larynx (Ellis and Solander, 1786)	C	–	
Annelida: Polychaeta (worms)	*Harmothoe imbricata* (Linnaeus, 1766)	C	–	David and Krick, 2019
	Nereis pelagica Linnaeus, 1758	C	–	
	Dipolydora socialis (Schmarda, 1861)	C	–	David and Krick, 2019
	Phyllodoce maculata (Linnaeus, 1767)	C	–	David and Krick, 2019
Crustacea: Cirripedia (barnacles)	*Amphibalanus subalbidus* (Henry, 1973)	RE	Southern U.S.	see Table 3
Crustacea: Amphipoda (amphipods)	*Apocorophium acutum* (Chevreux, 1908)	C	–	
	Monocorophium insidiosum (Crawford, 1937)	C	–	
	Monocorophium acherusicum (Costa, 1853)	C	–	
	Grandidierella japonica Stephensen, 1838	NIS	Northwest Pacific	Trott et al. 2020; see Table 3
	Microdeutopus gryllotalpa Costa, 1853	NIS	Northeast Atlantic	
	Caprella equilibra Say, 1818	C	–	
	Caprella mutica Schurin, 1935	NIS	Northwest Pacific	
Crustacea: Isopoda (isopods)	*Ianiropsis serricaudis* Gurjanova, 1937	NIS	Northwest Pacific	Hobbs et al. 2015
Crustacea: Tanaidacea (tanaids)	*Tanais dulongii* (Audouin, 1816)	C	–	
Crustacea: Decapoda (crabs and shrimp)	*Hemigrapsus sanguineus* (de Haan, 1835)	NIS	Northwest Pacific	
	Carcinus maenas Linnaeus, 1758	NIS	Northeast Atlantic	
	Palaemon macrodactylus Rathbun, 1902	NIS	Northwest Pacific	Warkentine and Rachlin 2010, 2012
Bryozoa (bryozoans)	*Amathia gracilis* (Leidy, 1855)	C	–	
	Cryptosula pallasiana (Moll, 1803)	C	–	
	Bugula neritina (Linnaeus, 1758) (type N)	NIS	Unknown	Fehlauer-Ale et al. 2014
	Tricellaria inopinata d'Hondt and Occhipinti Ambrogi, 1985	NIS	Northwest Pacific	see Table 3
Entoprocta (entoprocts)	*Barentsia benedeni* (Foettinger, 1887)	NIS	Northeast Atlantic	
Chordata: Ascidiacea (sea squirts)	*Didemnum vexillum* Kott, 2002	NIS	Northwest Pacific	see text discussion
	Diplosoma listerianum (Milne-Edwards, 1841)	NIS	–	
	Styela clava Herdman, 1881	NIS	Northwest Pacific	
	Botrylloides violaceus Oka, 1927	NIS	Northwest Pacific	
	Botryllus schlosseri (Pallas, 1766)	NIS (see Comments)	Northeast Atlantic (and native)	Populations in New England consist of both non-native and native clades (Yund et al. 2015)
	Ascidiella aspersa (Muller, 1776)	NIS	Northeast Atlantic	
	Ciona intestinalis (Linnaeus, 1767)	NIS	Northeast Atlantic	Hudson et al. 2020
Chlorophyta (green algae)	*Cladophora sericea* (Hudson) Kutzing, 1843	C	–	
	Bryopsis plumosa (Hudson) C. Agardh, 1823	C	–	
	Ulva compressa Linnaeus, 1753	C	–	
	Ulva lactuca Linnaeus, 1753	C	–	
	Ulva linza (Linnaeus) J. Agardh, 1883	C	–	
	Ulva rigida C. Agardh, 1823	C	–	
	Codium fragile subsp. *fragile* (Suringar) Hariot, 1889	NIS	Northwest Pacific	
Rhodophyta (red algae)	*Dasysiphonia japonica* (Yendo) H.-S.Kim, 2012	NIS	Northwest Pacific	
	Grateloupia turuturu Yamada, 1941	NIS	Northwest Pacific	

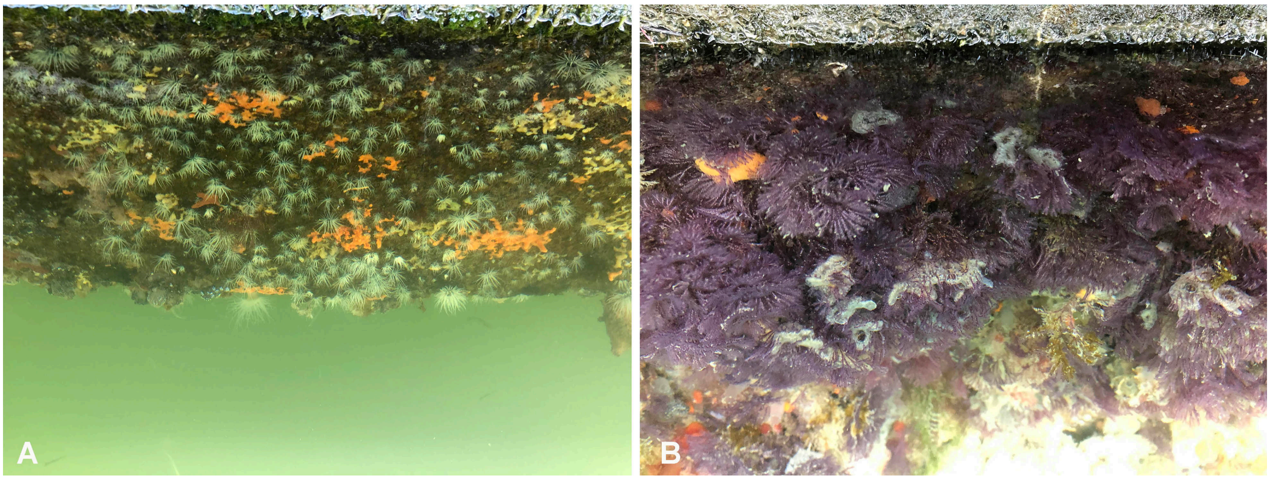

Figure 3. A dense fringe of the non-native sea anemone *Diadumene lineata* covering the waterline on the side of a floating pontoon, with scattered orange colonies of the non-native seasquirt *Botrylloides violaceus*, at Stamford CT, 19 August 2019 (Station BYH). B. A dense population of the non-native bryozoan *Bugula neritina* at Wakefield RI, 17 August 2019 (Station PTJ). Photographs by J.T. Carlton.

Table 3. New NIS records and new NIS distribution records in RAS 2019 conducted in southern New England and New York. For abbreviations and locations see Table 1 and Figure 1.

Species	First record in Southern New England/New York	Reference	RAS 2019 records
*Asian bryozoan *Tricellaria inopinata*	2010 (MA: Woods Hole) and 2013 (RI and south to Norwalk, CT)	Wells et al. 2014 (RI records); R. Whitlatch (CT records, *pers. comm*. 2013)	Range expansion to State of New York (SHS), and short-distance expansion west to Stamford, Connecticut (BYH).
**Anemone (southern U.S.) *Aiptasiogeton eruptaurantia*	2010 (PTJ)	Wells et al. 2014	Known at PTJ from 2010–2013 (Wells et al. 2014), and found here again in 2019; new population discovered at MBG. Previously known from Chesapeake Bay and south.
**Barnacle (southern U.S.) *Amphibalanus subalbidus*	2019 (herein, SBJ)	(herein)	First record for Long Island Sound (NY); previously known from the Hudson River and south.
*Asian amphipod *Grandidierella japonica*	2013 (Connecticut)	Trott et al. 2020 and herein	First records for STB and for GKS

* Introduced species
** Southern Atlantic U.S. coastal species not native to New England or New York, generally from Delaware and Chesapeake Bays south to Florida.

intertidal shores, oligohaline estuaries, and salt marshes (Carlton 2014). These have included the shrimp *Palaemon macrodactylus* Rathbun, 1902 (Warkentine and Rachlin 2010, 2012), the seaweed *Dasysiphonia japonica* (Yendo) H.-S. Kim, 2012 (Schneider 2010) and the amphipod *Grandidierella japonica* (Trott et al. 2020), all native to the Northwest Pacific, and all of which we found in the current survey.

Additional work since RAS 2003 has also documented the distribution of previously established invasions in the region, such as the ascidians *Didemnum vexillum* Kott, 2002, in Narragansett Bay RI (Auker 2019) and *Styela clava* in Long Island Sound (Brunetti and Cuomo 2014). During the 2019 survey, we did not encounter in the 2019 survey several NIS newly reported in New England. These include the brown seaweed *Colpomenia peregrina* (Sauvageau, 1927) (Green-Gavrielidis et al. 2019) and the polychaete *Polydora neocaeca* Williams and Radashevsky, 1999 (Malan et al. 2020), both also from the Pacific Ocean, as well as the southern Atlantic U. S. mussel *Mytilopsis leucophaeata* (Conrad, 1831), documented in a brackish-water location in Long Island Sound (Richardson and Hammond 2016) not surveyed by us.

As noted above, we have conducted RASs in the Northwest Atlantic from the Maine-Canada border to New York since 2000. A summary of NIS diversity and invasion patterns over this time and range is in preparation, including comparisons of the present survey data to earlier data from 2000–2013 in southern New England and from 2003 in Long Island Sound and New York (Pederson et al. *in preparation*). This said, we take the opportunity to note that one of the most iconic invasions of the Northwest Atlantic in the late 20th century, the Japanese ascidian *Didemnum vexillum*, failed to be detected at any of our sampling stations south and west of Narragansett Bay RI in August 2019, although it remains common to abundant elsewhere in New England and in Eastern Canada (Bullard et al. 2007; Kaplan et al. 2018; Carman et al. 2019). Auker (2019) has noted the decline of *D. vexillum* in Narragansett Bay, in southern New England, between 2005 and 2015. It was first found in Long Island Sound in 2000–2001 (Osman and Whitlatch 2007; Stefaniak and Whitlatch 2014) and was uncommon in our 2003 survey (Pederson et al. 2005).

Several species formerly regarded as non-native or cryptogenic in New England have, over the past 20 years, proven to be native, at least in part. In the Northwest Atlantic, one of the most common fouling species is the ascidian *Botryllus schlosseri*. As noted above, genetic studies reveal that *B. schlosseri* in New England consists of both native and introduced metapopulations (Yund et al. 2015), which cannot be distinguished in the field. Haydar et al. (2011) concluded that the abundant ascidian *Molgula manhattensis* (DeKay, 1843) is native in the Northwest Atlantic Ocean. While the hydroid *Obelia geniculata* (Linnaeus, 1758), not found by us in the current survey, is widely regarded as having been distributed globally in ship fouling, genetic work suggests that it is naturally distributed across the North Atlantic. However, an isolated Canadian haplotype of *O. geniculata* has been documented by genetic analysis as occurring in southern New England (Govindarajan et al. 2004), suggesting that intracoastal anthropogenic dispersal can and does occur. The widespread rocky intertidal snail *Littorina saxatilis* (Olivi, 1792) further appears to be primarily naturally distributed across the North Atlantic from Europe to North America, although an Irish haplotype was detected in Long Island Sound (Panova et al. 2011). Similar results for other widespread North Atlantic species with a long history of ship-mediated dispersal can be expected with future molecular work. Allochthonous haplotypes (from Canada, Europe or elsewhere) of widespread species will likely continue to be found in New England.

We conclude by noting that numerous groups of biofouling (as well as benthic and planktonic) invertebrates remain increasingly unassessed worldwide in terms of biodiversity, distributional changes in time and space, and the arrival of new invasions (Carlton and Fowler 2018). Even though the Rapid Assessment Surveys employed a large and experienced team of specialists conducting surveys in an area with a long history of species records dating back to the early 1800s, there remain large knowledge gaps of numerous taxonomic groups for New England and elsewhere. These include some of the most common taxa encountered in marine biofouling communities, including foraminifera, other "protists", sponges, hydroids, flatworms, oligochaetes, nemerteans, nematodes, benthic copepods and many others. The lack of biogeographic, historical and taxonomic resolution of these and other taxa, and thus the inevitably large number of cryptogenic species, both underscores our underestimation of the number and diversity of non-native species and limits understanding of their ecological and environmental impact.

Acknowledgements

We are grateful to the owners and operators of the 10 marinas visited from Rhode Island to New York for permission to collect at their sites. We thank the Williams College – Mystic Seaport Maritime Studies Program (Mystic CT), Dr. John Waldman of Queens College, and Dr. Carol Thornber of the University of Rhode Island for the use of laboratory facilities. The Williams-Mystic Program generously permitted loan of microscopes, fiber-optic lights, and other equipment, that were used at the Queens College campus. A core group of marine biologists and taxonomists, some of whom have been members of the RAS expeditions since 2000, volunteer many days (and, in aggregate, over the decades, many months) of their time to the collection, sorting, and identification of hundreds of species. We thank Paul Fofonoff, Evangelina Schwindt, and an anonymous reviewer for thorough reviews of the manuscript. Finally, we are deeply grateful to Michele Tremblay of Naturesource Communications, Penacook, New Hampshire, for extensive logistical and financial management support.

Funding Declaration

Funding support was provided by the MIT Sea Grant College Program, Rhode Island Sea Grant College Program, Connecticut Sea Grant College Program, Massachusetts Department of Conservation and Recreation, the New York Department of Environmental Conservation and the Northeast Aquatic Nuisance Species Panel. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Ethics and Permits

This work was conducted under scientific collecting permits from the States of Rhode Island, Connecticut, and New York and from the U.S. National Park Service. The authors have complied with all policies relative to the collection and handling of marine species, and no ethics approval was required.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Southern New England-New York Rapid Assessment Survey 2019 Survey. Introduced species by survey station (associated salinity and temperature data shown).

Table S2. Southern New England-New York Rapid Assessment Survey 2019 Survey. Cryptogenic species by survey station (associated salinity and temperature data shown).

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