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Rapid Communication

Poleward range expansion of a non-indigenous bryozoan and new occurrences of exotic ascidians in southeast Alaska

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Abstract

We report a first record of the widely invasive bryozoan *Bugula neritina* in Ketchikan, Alaska (USA), on Revillagigedo Island (southeast Alaska). This represents the northernmost record of this fouling organism in the northeast Pacific Ocean. We also report a new occurrence of the solitary ascidian *Ciona savignyi* not found in Alaska since 1903, along with recent occurrences of the invasive colonial ascidians *Botryllus schlosseri* and *Botrylloides violaceus* in new localities. The high level of vessel traffic in this region and the precedent for historical ship-borne invasions worldwide suggest that future population growth and establishment of these taxa in the Ketchikan area could set the stage for further poleward range expansion, highlighting the need for continued monitoring.

Key words: invasive species, non-native, introduced species, North America, biofouling, Northeast Pacific, citizen science

Introduction

Southeast Alaska, U.S.A—particularly the city of Ketchikan, as the most south-eastern city in the state—is a key location in Alaska for early detection of marine species with the potential to spread poleward from lower latitudes. Moreover, non-indigenous species (NIS) may be particularly problematic here. Alaska has fewer marine NIS currently than other coastal U.S. states, and they could disrupt near-pristine ecosystems while impacting the state's substantial maritime economy (Fay 2002). Vessel traffic is a predominant vector contributing to the spread of NIS worldwide (Ruiz et al. 2000, 2013, 2015). Ketchikan has a long history of shipping from logging and fishing, joined by the now-ubiquitous summer cruise ship traffic (NBIC 2018). The city is a first port of call for many cruise ship itineraries, and it is the first city in Alaskan waters for vessels traveling north along the inside passage, from the U.S. state of Washington and the Canadian province of British Columbia (McGee et al. 2006). As such, it has the potential to serve as a key link and hub for ship-borne transport of marine NIS.

We present results for four widely introduced marine invertebrate taxa—three ascidians and a bryozoan. These taxa are common in fouling and hard-substrate coastal communities around the globe, but they have been either absent or rare in Alaskan waters (Table 1). Focal taxa include the upright bryozoan *Bugula neritina* (Linnaeus, 1758), the solitary ascidian *Ciona savignyi* Herdman, 1882, and two colonial ascidians, *Botryllus schlosseri* (Pallas, 1766) and *Botrylloides violaceus* Oka, 1927. Published reports have noted the presence of *B. schlosseri* and *B. violaceus* in the region using data collected in the

Table 1. Non-indigenous sessile marine invertebrates included in this study with year of first live record in Alaskan waters.

Taxon	Location	1st record	Reference
Tunicata			
Botrylloides violaceus	Tatitlek	1999	Hines and Ruiz 2000
	Sitka	2001	Ruiz et al. 2006
	Ketchikan	2003	Ruiz et al. 2006; Simkanin et al. 2016; this study
Botryllus schlosseri	Sitka	2001	Ruiz et al. 2006
	Ketchikan	2010	Simkanin et al. 2016; this study
Ciona savignyii	Loring	1903	Ritter 1913
	Ketchikan	2016	this study
Bryozoa			
Bugula neritina	Ketchikan	2015	this study

surveys we describe here (Simkanin et al. 2016). We therefore do not present first records for these two taxa, but rather provide further detail on detection frequency, localities, and patterns of potential establishment. Beyond our brief introduction to each taxon's status in the region, detailed reviews of these species' ecological impacts, invasion histories, and regularly updated geographic distributions are provided by the Smithsonian Institution's National Marine and Estuarine Species Information System (Fofonoff et al. 2018).

The upright, branching bryozoan *Bugula neritina* is globally distributed and has been found in the northeast Pacific Ocean as far north as Washington in the U.S.A. and Vancouver Island, British Columbia (B.C.), Canada, roughly 560 km south-southeast of Ketchikan at 50ºN (Cohen and Carlton 1995; Wonham and Carlton 2005; Gartner et al. 2016). Though abundant in California, records to the north are limited and the extent of its establishment north of California remains unclear. Live colonies of *B. neritina* have not been previously detected in Alaskan waters, although researchers have found dead colonies on transient boat hulls (Ashton et al. 2014). Its origin remains unknown, and it is considered cryptogenic across much of the globe, but non-indigenous in the northeast Pacific (Fofonoff et al. 2018). In the western Pacific Ocean, *B. neritina* is documented as far north as South Korea (38ºN; Park et al. 2017). The northernmost record from the Atlantic Ocean is Plymouth, U.K. (50ºN; Ryland 1960). *Bugula neritina* encompasses an as-yet unresolved species complex, possibly including three or more cryptic species that appear morphologically identical (Fehlauer-Ale et al. 2014).

The solitary ascidian *Ciona savignyi* is thought to originate from a native range in Japan and is now found as far north as Vostok Bay, Russia in the northwest Pacific Ocean (Zvyagintsev et al. 2007). Although non-indigenous along much of the northeastern Pacific, it is considered cryptogenic in Alaska, and its current range is uncertain, due to the rarity of early specimens (Lambert 2003). The species is firmly established to the south throughout California where it is non-indigenous (Cohen and Carlton 1995; Lambert and Lambert 1998; Lambert 2003; Blum et al. 2007). The current northeast Pacific range extends from southern California to Alaska, but no specimens have been found in Alaska since the first collection in Loring, Alaska in 1903 (Ritter 1913; note Loring is roughly 30 linear km from Ketchikan on Revillagigedo Island). The most recent record north of Puget Sound is a 2016 specimen collected in Bella Bella, B.C., 420 km south-southeast of Ketchikan (RBCM 2018). The Loring, Alaska specimen was originally recorded as *C. intestinalis* (Linnaeus, 1767) and revised by Hoshino and Nishikawa (1985). In 2008, three specimens of an unknown *Ciona* species of unknown origin were discovered in the seawater system of the University of Alaska Fairbanks' Marine Center in Seward. Genetic analysis could not definitively identify the material to species (S. Cohen, *personal communication*). Monitoring in the area has not reported any *Ciona* species since then, so this study represents the first record in Alaska since 1903, and a new locality record for the species in the state.

The colonial ascidian *Botrylloides violaceus* is a well-known, often problematic, fouling species that may impact native taxa via competition (e.g., Myers 1990; Osman and Whitlatch 1995; and see Fofonoff et al. 2018 for a review of impacts). It is native to the northwest Pacific and now broadly established around the globe, including in the northeast Pacific from Baja California through British Columbia, where it has been found as far north as Haida Gwaii, 150 km south of Ketchikan (Lambert and Sanamyan 2001; Bock et al. 2011; Gartner et al. 2016). *Botrylloides violaceus* was first found in Alaska in 1999 as newly settled juveniles on fouling panels in Tatilek, roughly 1000 km northwest of Ketchikan (Hines and Ruiz 2000; Table 1). Reproductive adults have since been documented in multiple surveys in Sitka, and it is established in many harbors there (Ruiz et al. 2006). It was first found in Ketchikan in 2003 (Table 1).

Another colonial ascidian, *Botryllus schlosseri,* is a non-indigenous species in northeast Pacific waters (reviewed in Fofonoff et al. 2018). It comprises a species complex (Nydam et al. 2017) first observed in the northeastern Pacific in 1947 (San Francisco Bay; Cohen and Carlton 1995). The known range of *B. schlosseri* in the eastern Pacific extends from Ensenada, Mexico (Lambert and Lambert 1998) northward to its first record in Alaska, where it was identified from samples collected in 2001 from Sitka Sound, roughly 250 km north of this study (Ruiz et al. 2006). As with *B. neritina,* only dead individuals of *B. schlosseri* were found on boat hulls in Ketchikan before the studies included here (Ashton et al. 2014). It was first recorded live in Ketchikan in 2010 (Simkanin et al. 2016), discovered through the citizen-science monitoring project we describe here.

We include results from three different surveys of marine fouling species in this gateway region. Findings include a new record for the state, *B. neritina,* new localities for *C. savignyi* and *B. schlosseri* (including the first specimen of *C. savignyi* found in Alaska in over one hundred years), and further detail of the distribution and abundance of *B. violaceus*. Taken together, our results underscore the potential for range expansion of these common marine invaders. They also highlight the capacity of this region to become a new source from which these taxa may spread further.

Methods

We report findings from three distinct surveys of marine fouling communities that used standardized artificial substrates as passive collectors for the colonization of sessile marine invertebrates. These included (1) 2003 and 2013 NIS detection surveys, (2) an annual citizen-science monitoring program established in 2007 (PlateWatch 2017) with trained local residents, and (3) a broad-scale experiment, part of which was located in the Ketchikan area of Revillagigedo Island from 2015 to 2016. Survey times, replicates, and locations around the Ketchikan region differed, but each survey deployed bare, pre-sanded 14 cm × 14 cm PVC settlement panels face-down on weighted lines suspended from floating docks at 1 ± 0.2 m depth. Figure 1 shows specific survey locations, and Tables 2 and 3 provide the numbers of panels deployed for each survey. For survey type (3), a factorial experiment manipulated two factors. The first was predator access to settlement panels, accomplished with mesh caging (0.6 cm openings) in three treatments: full cage, no cage, and a partial cage treatment as a procedural control. The second factor manipulated biomass removal to reduce competition for space, with 0, 20, or 60% of biomass removed once monthly prior to the 2015 retrieval of panels. We report results for *B. schlosseri* and *B. violaceus* from these 2015 experiments, as these taxa were the only ones sufficiently common to test factor effects.

We allowed communities of sessile invertebrates to develop on initially bare panels for three months prior to analysis, except for one year-long deployment from June 2015 to June 2016 (reported as 2016 surveys). We deployed survey panels in June to capture summer peaks in invertebrate recruitment that are common for many marine taxa in temperate regions (Watson and Barnes 2004; Broitman et al. 2008). The Plate Watch program (survey type 2 above) suspended two settlement panels from floating docks at one site (CM) and eight at another (BH), one to three times per year (March, June, and September), with priority being given to the summer time period from June to September. For survey types (1) and (3) above, we examined each community live under a stereo microscope after retrieving panels from the field, identifying organisms to the lowest possible taxonomic level. We preserved a representative subset of each species for further identification and confirmation by taxonomists at the Smithsonian Environmental Research Center (SERC). For the Plate Watch citizen science surveys (2, above), trained volunteers visually examined each panel for specific NIS in the field, focusing especially on tunicates. Participants provided high-resolution photographs electronically to SERC scientists, and sent physical specimens when necessary for confirmation of identifications.

Since the 2016 surveys analyzed panel communities that had developed for a full year, these panels were exposed to more variable environmental conditions than other surveys, and potentially more intense biotic interactions at later successional stages. Environmental monitoring data (measured with a YSI® Pro 2030) from the 2015 to 2016 surveys indicated conditions at the 1m deployment depth during the summer (June to September 2015) ranged from 12.5 to 17.0 °C and, for salinity, from 21 to 28 ppt across the sites. Full year ranges in temperature and salinity reflected winter minima, spanning 6.0 to 18.0 °C and 15 to 28 ppt, respectively.

Results

Bugula neritina

We first detected *B. neritina* in 2015 at Bar Harbor Marina (Table 2). During that survey, we found one colony of this upright bryozoan, which had recruited and grown between June and September on one panel

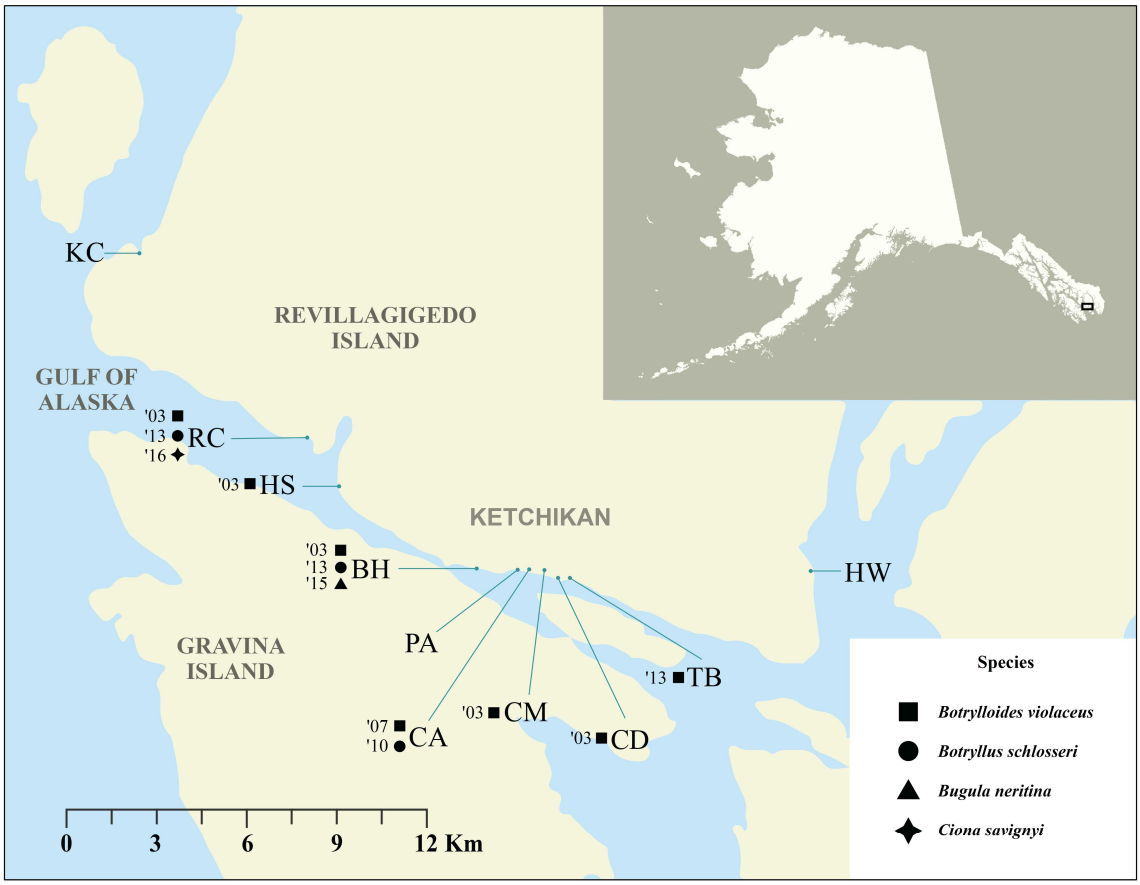

Figure 1. Species distribution and year of first detection since surveys began in 2003 in the Ketchikan region of southeast Alaska, U.S.A. Site abbreviations: Knudson Cove Marina (KC), Refuge Cove Marina (RC), Homestead Skiffs (HS), Bar Harbor Marina (BH), Promech Air (PA), Carlin Air (CA), Casey Moran (CM), Cruise Dock (CD), Thomas Basin (TB), and Hole In the Wall Marina (HW). All sites except CA were first surveyed in 2003. CA surveys began in 2007. GPS coordinates are given in Supplementary material, Table S1.

Table 2. Detection of NIS from 2003, 2013, 2015, 2016 surveys. Entries give the proportion of panels on which focal species were present from the year of first detection, with the total number of panels deployed in parentheses. For simplicity, when taxa were not detected prior to a given survey year, the columns of zeros not shown. Panels were deployed for 3 months except in 2016, in which panels were deployed for 12 months.

Sites	*Botrylloides violaceus*				*Botryllus schlosseri*			*Ciona savignyi*	*Bugula neritina*	
	2003	2013	2015	2016	2013	2015	2016	2016	2015	2016
BH	0.40(10)	0.64(39)	0.69(55)	0.11(55)	0.26(39)	0.44(55)	0.47(55)	0(55)	0.02(55)	0(55)
RC	0.90(10)	0.46(41)	0.45(55)	0.05(55)	0.07(41)	0.02(55)	0 (55)	0.04(55)	0(55)	0(55)
KC	0(10)		0(55)	0(55)		0(55)	0 (55)	0(55)	0(55)	0(55)
HS	0.07(10)	0.47(36)			0.03(36)					
HW	0(10)									
CM	0.60(10)									
PA	0(10)									
CD	0.40(10)									
TB	0(10)	0.22(41)			0(41)					
CA		0.69(39)			0.03(39)					

(image of colony in Figure 2A). This panel was a procedural control open to predators. We did not observe any reproductive structures (ovicells) present on this specimen (Figure 2A). The species was not found again in subsequent surveys in 2016 (Tables 2 and 3).

Table 3. Detection of NIS from citizen science monitoring surveys. Data are from annual surveys spanning 2007 to 2016 at two sites. Data depict the proportion of panels deployed that contained at least one individual or colony of the given taxon after three months, with the number of panels deployed in parentheses. Note in 2013, these surveys were replaced with the more intensive sampling reported in Table 2. Volunteers did not collect data for Bar Harbor Marina in 2012 and 2016, indicated with "NA" (not available). For survey details see www.platewatch.nisbase.org.

	Carlin Air (CA)				Bar Harbor Marina (BH)			
Year	***Botrylloides violaceus***	***Botryllus schlosseri***	***Ciona savignyi***	***Bugula neritina***	***Botrylloides violaceus***	***Botryllus schlosseri***	***Ciona savignyi***	***Bugula neritina***
2007	0.63 (8)	0 (8)	0 (8)	0 (8)	0 (2)	0 (2)	0 (2)	0 (2)
2008	0.38 (8)	0 (8)	0 (8)	0 (8)	0 (2)	0 (2)	0 (2)	0 (2)
2009	0.13 (8)	0 (8)	0 (8)	0 (8)	0 (2)	0 (2)	0 (2)	0 (2)
2010	1.0 (3)	0.33 (3)	0 (3)	0 (3)	0 (2)	0 (2)	0 (2)	0 (2)
2011	0.38 (8)	0 (8)	0 (8)	0 (8)	0 (2)	0 (2)	0 (2)	0 (2)
2012	0 (11)	0 (11)	0 (11)	0 (11)	NA	NA	NA	NA
2014	1.0 (2)	0 (2)	0 (2)	0 (2)	0.89 (9)	0 (9)	0 (9)	0 (9)
2015	1.0 (2)	0 (2)	0 (2)	0 (2)	0.10 (10)	0 (10)	0 (10)	0 (10)
2016	0.44 (9)	0 (9)	0 (9)	0 (9)	NA	NA	NA	NA

Ciona savignyi

The 2016 surveys were the first to detect the solitary ascidian *C. savignyi* in Alaskan waters since the first record in 1903, though it has been found to the south in British Columbia, Canada as previously discussed. In 2016, we found two individual adults alive and growing in separate experimental panel communities, both within cages excluding predators (Table 2). Both individuals were 4 to 5 cm in body length, with sperm ducts visible upon dissection. A representative image of the species is shown in Figure 2B, as the two specimens we collected photographed poorly after preservation.

Botrylloides violaceus

Beginning in 2003, surveys revealed the presence of *B. violaceus* at five of nine survey sites in the Ketchikan area (Table 2). Through citizen-science surveys, we detected *B. violaceus* on 63% of panels at the Carlin Air (CA) site in 2007, the first year of monitoring. It was present in all but one of the following years at this location (2012; Table 3). The experimental surveys in 2015 (a three-month deployment) and 2016 (a 12-month deployment) revealed the continued presence of *B. violaceus* at Bar Harbor (BH) and Refuge Cove Marinas (RC; Table 2). In 2015 surveys, predator treatment, biomass removals, and the interaction of these factors had no detectable effect on the presence or cover of *B. violaceus* at RC and BH (*ANOVA*; in all cases $p > 0.41$). The frequency of *B. violaceus* at both sites declined markedly in 2016 relative to 2015 (BH: 69% to 11% of panels; RC: 45% to 5% of panels). This species was not found at Knudson Cove Marina (KC) in any survey through 2016.

Botryllus schlosseri

We did not detect *Botryllus schlosseri* until September 2010 when it was found via citizen science monitoring at Carlin Air (Table 3). It was not found again until 2013, possibly due to the more extensive sampling effort at that time (Tables 2, 3). Surveys in 2013 revealed *B. schlosseri* present at all five survey sites (Table 2). *Botryllus schlosseri* was rare in 2015 and 2016 surveys, except at Bar Harbor Marina where it was present on nearly half of all panels in both years (Table 2). Cage treatments influenced *B. schlosseri* cover, but only in that full and cage-control (partially caged) panels had equivalent, and substantially less, cover (both means = 0.12 ± 0.09 SD) than open panels (mean cover: 0.39 ± .023 SD), suggesting cage artifacts rather than predator effects. Observations of *B. schlosseri* settled on or grown into caging suggest that bi-weekly cage maintenance (scrubbing) and removal of the panels from the cages during retrieval may have reduced its cover in those treatments. There was no effect of biomass removal or the interaction between treatments on cover or presence of *B. schlosseri* (*ANOVA*, $p > 0.34$ in all cases).

Discussion

Findings from these surveys in the Ketchikan region of southeast Alaska reveal the new northernmost occurrence of *Bugula neritina* in the eastern Pacific based on the first live specimen found in Alaskan waters. We also report the first specimen of *Ciona savigni* collected in Alaska in over one hundred years. Additionally, results show temporal variability in frequency but consistency in the presence of *Botrylloides violaceus* and *Botryllus schlosseri* at a subset

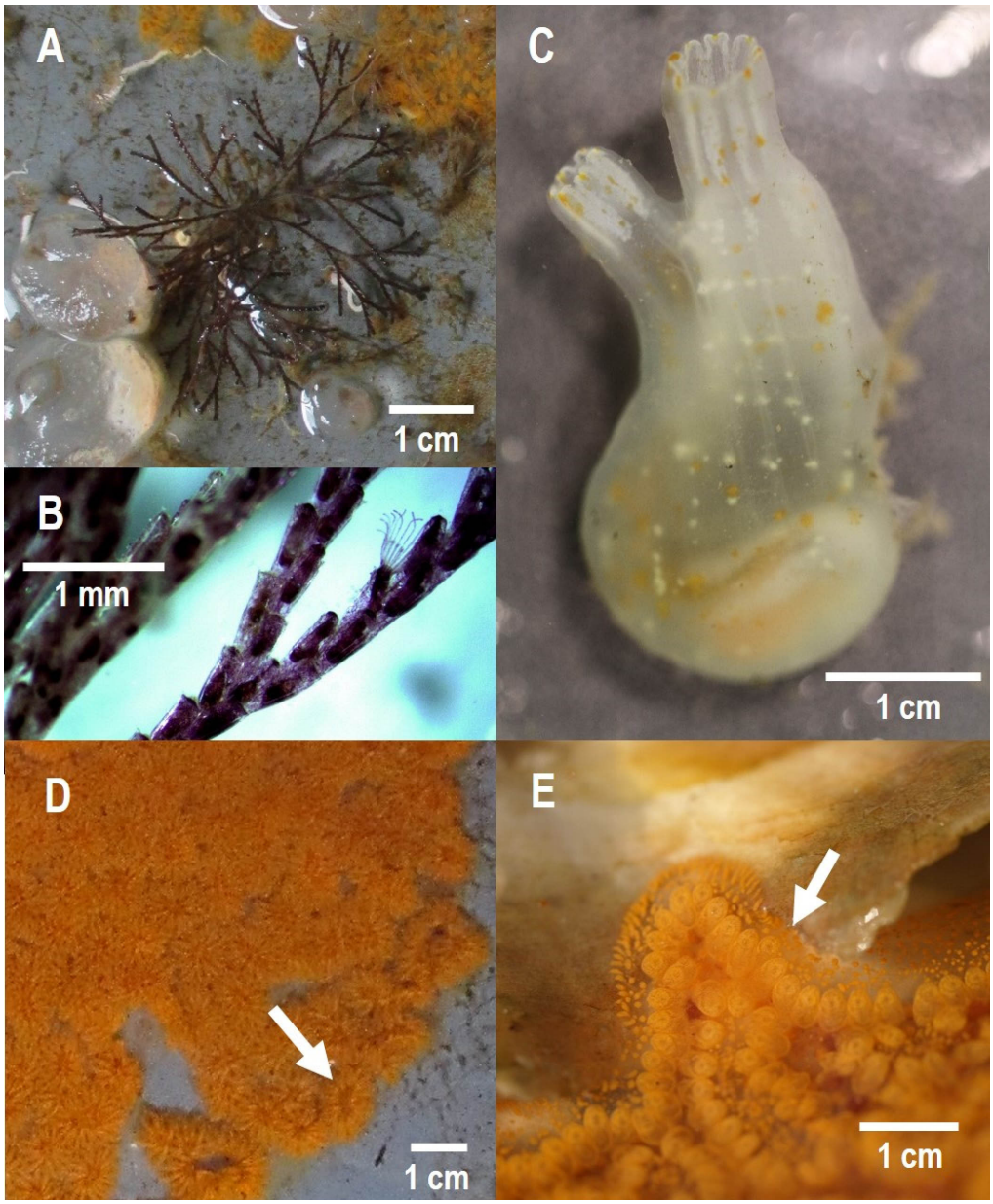

Figure 2. Images of four non-indigenous marine species (one bryozoan and three ascidians) detected on fouling panels in and around Ketchikan, Alaska, U.S.A. A. Depicts a *Bugula neritina* specimen collected at Bar Harbor Marina in 2015. This bryozoan species is brick red or purple and does not have spines or avicularia. B. Close-up of live *B. neritina* zooids showing distinguishing color, lack of avicularia, and lophophore (tentacle ring) from a specimen collected in San Francisco Bay, California. C. *Ciona savigni,* a solitary ascidian with clear, smooth, vase shaped body and a transparent soft tunic with white pigmented flecks in the body wall. The color of the end of the vas deferens is white (internal, not shown). The specimen here is photographed live and is representative of the species. D. *Botryllus schlosseri*. The arrow emphasizes the star or flower-shaped orientation of the zooids. Color in this species is highly variable and may also be yellow, purple, red, brown, or black. E. *Botrylloides violaceus*. Note the chain-like rows of zooids and solid color, which can be purple, red, orange, yellow, or brown. Photo credits: D. Lopez (A, D), L. McCann (B), M. Frey (C) and G. Freitag (E).

of locations in the region, suggesting populations of these non-indigenous ascidians may be established at these sites. Taken together, these findings underscore the potential for these commonly invasive marine species to establish in and expand their ranges further from this important gateway region in the Gulf of Alaska.

Both colonial ascidians, *B. violaceus* and *B. schlosseri,* can be dominant competitors for space and reach

biomass levels capable of impacting shipping, fishing, aquaculture, and native marine invertebrate communities (reviewed in Fofonoff et al. 2018). Fouling by these taxa can also reduce growth of ecologically important seagrass (Wong and Vercaemer 2012). *Botrylloides violaceus* in particular appears to have established at sites in the harbor areas with highest traffic of recreational boats near the town of Ketchikan proper (particularly in recent years). It was present consistently since its appearance in our first surveys in 2003 at some of these sites (CA, BH; Tables 2, 3). We found the previously rare *B. schlosseri* regularly at Bar Harbor Marina beginning in 2013. The 2015 to 2016 surveys revealed an interesting, but possibly transient, shift in frequency from *B. violaceus* to *B. schlosseri* at Bar Harbor Marina. A general decline in *B. violaceus* over the same period occurred at Refuge Cove Marina, with no concurrent increase in *B. schlosseri* (Table 2). This pattern could be due to the later stage (12-months) of community development for panels sampled in 2016, but further exploration is needed to test that hypothesis. It is possible that our observed decline in frequency of *B. violaceus* can be attributed to the time of sampling and not necessarily a persistent decline. For example, the reduction in *B. violaceus* at Bar Harbor Marina could indicate an over-winter mortality cycle, potentially linked to low salinity during rainy winter months. Over the winter of 2015–2016, temperature reached a minimum of 6.0 °C. This could reduce growth of both *B. violaceus* and *B. schlosseri.* Salinity reached a minimum of 17.0 ppt, which appears more likely to negatively impact *B. violaceus* due to its somewhat lower salinity tolerance (Epelbaum et al. 2009). Both colonial ascidian species remained absent at other sites, including the third experimental site in the most recent survey years (2015–2016, KC; Table 2). Notably, this site is the farthest from the city of Ketchikan, and its busy cruise ship port, of the three sites surveyed in these years (Figure 1).

Whether the other two taxa, *C. savignyi* and *B. neritina*, are established remains unknown. However, their extremely low frequency (one or two specimens) in the surveys with the highest level of per-site replication (55 panels per site, Table 2) suggests that such establishment may not yet have occurred. There remains the potential for ocean warming driven by climate change to facilitate establishment—and potentially even further poleward range expansion—of both of these often-problematic species (Sorte et al. 2010). Elsewhere when abundant they are known to dominate biomass in hard-substrate communities and outcompete native biota (e.g., Sutherland and Karlson 1977; Winston 1982). *Bugula neritina* can impact fisheries and aquaculture by fouling gear (Hodson et al. 1997; de Sá et al. 2007). It is a strong competitor in benthic communities and its reproduction may be enhanced by increased water temperatures (Sutherland and Karlson 1997; Sorte and Stachowicz 2011). A morphologically very similar congener of *C. savignyi*, *C. robusta* is known to have substantial economic impacts via fouling of fishing or aquaculture gear in several parts of the world (Castilla et al. 2005; Robinson et al. 2005; Rocha et al. 2009). Continued monitoring in the region could be particularly important given such negative consequences of these species' invasions elsewhere.

There are numerous hypotheses regarding the potential for biotic interactions to influence the spread of invasive species, whether negatively via predation and competition (e.g., Freestone et al. 2011, 2013) or positively via facilitation (e.g., Rodriguez 2006). We found no evidence that local predation in Ketchikan limited the species we consider here. Yet the question warrants further study (and the only two specimens of *C. savignyi* we found were in predator-exclusion cages). The capacity of predators to control NIS varies even across tropical and sub-tropical locations where predation is generally considered intense. For example, *B. neritina* and *Botrylloides nigrum* (a close relative of *B. violaceus* and *B. schlosseri*) appear to be poorly controlled by fish predators in Pacific Panama (Jurgens et al. 2017), yet predation affects multiple aspects of their population dynamics in Brazil's Southwestern Atlantic Ocean (Oricchio et al. 2016a, b; Vieira et al. 2012, 2016). Importantly, we have observed leather sea stars (*Dermasterias imbricata*) consuming *B. violaceus* and *B. schlosseri* both directly and via time-lapse photography on benthic settlement panels in Ketchikan (G Freitag and L Jurgens, *personal observation*). Echinoderms are often key consumers in temperate regions (e.g., Jurgens et al. 2015; Gravem and Morgan 2017), and their potential to influence benthic NIS establishment bears further investigation. Sea star predation may not be detected as well on suspended panels, but their effects could be pronounced in hard-bottom habitats. Additionally, facilitation can be strong in temperate marine systems (e.g., Jurgens and Gaylord 2016, 2018), and may benefit both native taxa and NIS by offering substrate and refugia from predators or abiotic stressors (Altieri et al. 2010). Targeted experiments in the region could help untangle how these types of biotic interactions may influence population dynamics of the four NIS we consider here.

Intense abiotic stressors, such as extreme low salinities or temperatures, could also limit population expansion of these NIS. Extreme low salinity events have been associated with large reductions in *B. neritina* and *C. savignyi* populations in San Francisco Bay

(Chang et al. 2018). Ketchikan receives an enormous amount of rain annually and there is substantial tidal mixing (Weingartner et al. 2009), which could potentially limit these taxa, particularly in shallow waters. Temperature and salinity could also influence establishment north of Ketchikan. Minimum temperatures in the Gulf of Alaska appear relatively stable (~ 6 °C) as far north as Seward, but coastal margins of the Bering Sea have much lower annual minima (NOAA 2018). Low salinity extremes common in the Gulf of Alaska could reduce the likelihood of population establishment, particularly since many coastal areas already receive enormous freshwater runoff, which appears to be increasing with warming temperatures (Royer and Grosch 2006). Examining population responses to salinity variation could provide insight into the potential of low-salinity events to limit these species' establishment.

Findings from this collection of surveys demonstrate the efficacy of monitoring efforts, including those that engage local residents, in successfully detecting the presence of non-indigenous marine taxa. Citizen science monitoring can supplement more extensive scientific surveys both spatially and temporally, thereby facilitating the detection of new non-natives. The first detection of *B. schlosseri* in Ketchikan and of the invasive tunicate, *Didemnum vexillum* (Kott, 2002) in Sitka, Alaska occurred through this same Plate Watch program (Cohen et al. 2011). Continued monitoring in the region will be important to detect spatial population expansion and shifts in abundance. High recreational vessel traffic in the region could extend local distributions of NIS among sites. While we found these species on passive collectors near marinas and dock areas, they are also able to colonize natural substrate from nearby anthropogenic structure (Simkanin et al. 2012). Since any of these taxa could potentially impact the region's important fisheries and aquaculture activities via fouling, and may also displace native species, population expansion could be problematic at local scales and warrants continued investigation.

The establishment of any or all of these taxa in the Ketchikan region of southeast Alaska may be problematic at larger scales as well, due to the sheer volume of vessel traffic passing through the area (McGee et al. 2006). Both recreational and commercial vessels are potent vectors for introduction of NIS propagules to new sites and regions via secondary spread (Ruiz et al. 2000, 2013, 2015; Davidson et al. 2009; Kelly et al. 2013). Ketchikan's prominence as a first port of call for cruise ships and ferries passing into more northerly Alaskan waters with large ports (McGee et al. 2006) indicates a particular risk for poleward transport of these species, which could be further exacerbated by an increase in Arctic crossings made possible by climate warming (Miller and Ruiz 2014). These climate and vector-based threats underscore the risk that establishment of these NIS in the region could produce new source populations from which the species could further spread.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Occurrence of four non-native sessile marine invertebrate species colonizing harbors and floats of Ketchikan, Alaska, with site and survey information.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2018/Supplements/BIR_2018_Jurgens_etal_Table_S1.xlsx