Bering Sea Marine Invasive Species Assessment

Alaska Center for Conservation Science

Scientific Name: *Diplosoma listerianum*

Common Name *compound sea squirt*

Phylum	Chordata
Class	Ascidiacea
Order	Aplousobranchia
Family	Didemnidae

Final Rank 52.75

Data Deficiency: 0.00

Species Occurrence by Ecoregion

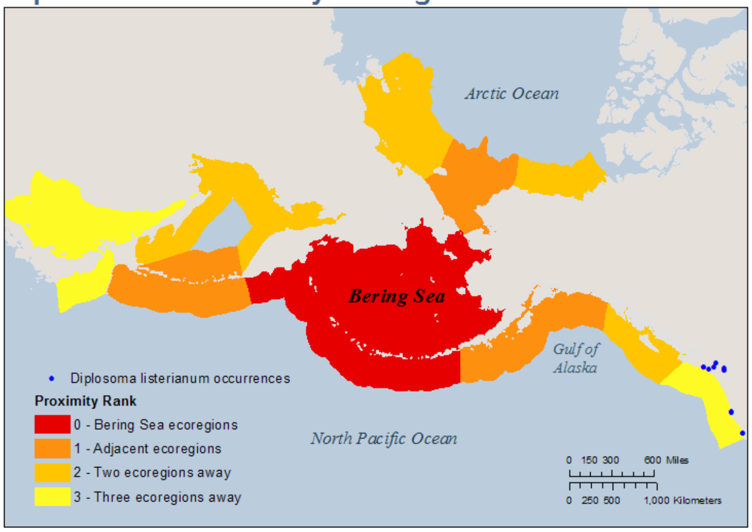

Figure 1. Occurrence records for non-native species, and their geographic proximity to the Bering Sea. Ecoregions are based on the classification system by Spalding et al. (2007). Occurrence record data source(s): NEMESIS and NAS databases.

Category Scores and Data Deficiencies

Category	Score	Total Possible	Data Deficient Points
Distribution and Habitat:	21.25	30	0
Anthropogenic Influence:	6.75	10	0
Biological Characteristics:	19.5	30	0
Impacts:	5.25	30	0
Totals:	52.75	100.00	0.00

General Biological Information

Tolerances and Thresholds

Minimum Temperature (°C)	-0.6	Minimum Salinity (ppt)	18
Maximum Temperature (°C)	30	Maximum Salinity (ppt)	40
Minimum Reproductive Temperature (°C)	15	Minimum Reproductive Salinity (ppt)	31*
Maximum Reproductive Temperature (°C)	NA	Maximum Reproductive Salinity (ppt)	35*

Additional Notes

D. listerianum likely refers to a complex of colonial tunicates that grow as thin, white mats on substrates and organisms. Their native range is uncertain, but they have likely been introduced to several regions including both coasts of North America, Hawaii, New Zealand, and South Africa. D. listerianum can foul cultivated shellfish and aquaculture equipment, as well as compete with other tunicates and benthic invertebrates.

Reviewed by Jennifer Dijkstra, Research Assistant Professor, School of Marine Science and Ocean Engineering, University of New Hampshire, Durham, NH

Review Date: 9/26/2017

1. Distribution and Habitat

1.1 Survival requirements - Water temperature

Choice: **B** Moderate overlap – A moderate area (≥25%) of the Bering Sea has temperatures suitable for year-round survival

Score: 2.5 of 3.75

High uncertainty? ✔

Ranking Rationale:
Temperatures required for year-round survival occur in a moderate area (≥25%) of the Bering Sea. Thresholds are based on geographic distribution, which may not represent physiological tolerances; moreover, models disagree with respect to their estimates of suitable area. We therefore ranked this question with "High uncertainty".

Background Information:
Based on this species' geographic distribution, temperature threshold is estimated to be between -0.6°C and 30.1°C (Zerebecki and Sorte 2011; Lord et al. 2015; Lord 2017). Sorte et al. (2011) conducted experiments on two different North American populations, and reported LT50 values of 29.1°C and 27.9°C for east coast (Massachusetts) and west coast (California) populations, respectively.

Sources:
Zerebecki and Sorte 2011   Lord 2017   Sorte et al. 2011   Lord et al. 2015

1.2 Survival requirements - Water salinity

Choice: **A** Considerable overlap – A large area (>75%) of the Bering Sea has salinities suitable for year-round survival

Score: 3.75 of 3.75

Ranking Rationale:
Salinities required for year-round survival occur over a large (>75%) area of the Bering Sea. Thresholds are based on geographic distribution, which may not represent physiological tolerances.

Background Information:
The salinity threshold for survival of D. listerianum is between 18 to 40 ppt (Fofonoff et al. 2003). In Shark Bay, Australia, colonies were retrieved from fouling plates at two sites with salinities between 38 and 42 ppt (Wyatt et al. 2005). The lower salinity threshold cited by Fofonoff et al. (2003) is based on the typical salinity of the Black Sea, where D. listerianum is established (Koukouras et al. 1995, qtd. in Fofonoff et al. 2003). Studies on other populations suggest that D. listerianum may be less tolerant of low salinities. In an experiment on cultured populations from Wales, 64% and 92% of colonies died after seven days when exposed to constant salinities of 27 and 20 ppt; mortality was 100% for both treatments after 10 days (Gröner et al. 2011). In contrast, colonies exposed to 34 ppt showed positive growth and negligible mortality over 14 days (Gröner et al. 2011).

Sources:
NEMESIS; Fofonoff et al. 2003   Wyatt et al. 2005   Gröner et al. 2011

1.3 Establishment requirements - Water temperature

Choice: D No overlap – Temperatures required for reproduction do not exist in the Bering Sea

Score: 0 of 3.75

High uncertainty? ✔

Ranking Rationale:

Temperatures required for reproduction do not exist in the Bering Sea. Thresholds are not based on physiological tolerances; we therefore ranked this question with "High uncertainty".

Background Information:

Sexual reproduction and larval development have been successfully conducted at temperatures between 16°C and 18°C (reviewed in Ryland and Bishop 1990). Minimum reproductive temperature for D. listerianum is 15°C (based on water temperature when larvae are released; Brunetti et al. 1988 qtd. in Fofonoff et al. 2003). This species depends on annual recruitment for population establishment. Osman et al. (2010) observed nearly complete recruitment failure when mean winter sea temperatures were below 4°C. Stachowicz et al. (2002) found a strong relationship between onset of recruitment and springtime (March 1st) water temperatures in Connecticut. D. listerianum recruited earlier in years when temperatures were warmer. For example, recruitment began as early as mid-May when temperatures were ~5°C, and as late as early October when March temperatures were 2.5°C (mean onset date: July 10th; Stachowicz et al. 2002).

Sources:

Osman et al. 2010   NEMESIS; Fofonoff et al. 2003   Ryland and Bishop 1990   Stachowicz et al. 2002

1.4 Establishment requirements - Water salinity

Choice: A Considerable overlap – A large area (>75%) of the Bering Sea has salinities suitable for reproduction

Score: 3.75 of 3.75

High uncertainty? ✔

Ranking Rationale:

Although exact salinity thresholds are unknown, this species is a marine organism that requires salinities > 27 ppt to survive and grow. We assume that this species can reproduce and develop in saltwater from 31 to 35 ppt; these salinities occur in a large (>75%) portion of the Bering Sea.

Background Information:

In an experiment on cultured populations from Wales, colonies exposed to ambient seawater (34 ppt) showed positive growth and negligible mortality over 14 days (Gröner et al. 2011). In contrast, colonies exposed to constant salinities of 27 and 20 ppt exhibited no or negative growth and high mortality rates (Gröner et al. 2011).

Sources:

Gröner et al. 2011

1.5 Local ecoregional distribution

Choice: D Present in an ecoregion greater than two regions away from the Bering Sea

Score: 1.25 of 5

Ranking Rationale:

Background Information:

Found in Peter the Great Bay (Sea of Japan, southern Russia), and on Vancouver Island, B.C.

Sources:

NEMESIS; Fofonoff et al. 2003

1.6 Global ecoregional distribution

Choice: **A** In many ecoregions globally

Score: 5 of 5

Ranking Rationale:
Wide global distribution.

Background Information:
Found on both the east and west coasts of North America, Central America, and South America. In Europe, occurs from Norway to the Mediterranean, and east to the Red Sea. Found in South Africa, Madagascar, and Tanzania. In Asia, occurs from Peter the Great Bay in southern Russia to Hong Kong, as well as in India. Found in Australia and New Zealand, and Pacific islands including Fiji, Tahiti, and Hawaii.

Sources:
NEMESIS; Fofonoff et al. 2003

1.7 Current distribution trends

Choice: **A** Recent rapid range expansion and/or long-distance dispersal (within the last ten years)

Score: 5 of 5

Ranking Rationale:
Evidence of rapid range expansion in northern Europe.

Background Information:
Although natural long-distance dispersal is limited in this species, its reproductive characteristics and fast growth rates suggest that rapid expansion and colonization of new habitats is possible (Vance et al. 2009; Marshall et al. 2003; Pérez-Portela et al. 2013). Recent range expansions have likely occurred in the UK and the Netherlands (Gittenberger et al. 2007; Vance et al. 2009).

Sources:
NEMESIS; Fofonoff et al. 2003 Marshall et al. 2003 Pérez-Portela et al. 2013 Vance et al. 2009 Gittenberger 2007

Section Total - Scored Points:	21.25
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

2. Anthropogenic Transportation and Establishment

2.1 Transport requirements: relies on use of shipping lanes (hull fouling, ballast water), fisheries, recreation, mariculture, etc. for transport

Choice: **A**

Has been observed using anthropogenic vectors for transport and transports independent of any anthropogenic vector once introduced

Score: 4 of 4

Ranking Rationale:
Can be transported through hull fouling and by attaching to natural rafts.

Background Information:
Hull fouling is suspected as a form of transportation (Pérez-Portela et al. 2013). Low-survival of larvae is expected in ballast water due to their short free-swimming stage. Adults are mostly sessile, but colonies attached to natural "rafts" (e.g. sea grass, drifting wood) can be transported variable distances without the use of anthropogenic vectors.

Sources:
NEMESIS; Fofonoff et al. 2003   Pérez-Portela et al. 2013

2.2 Establishment requirements: relies on marine infrastructure, (e.g. harbors, ports) to establish

Choice: **B**

Readily establishes in areas with anthropogenic disturbance/infrastructure; occasionally establishes in undisturbed areas

Score: 2.75 of 4

Ranking Rationale:
Introductions largely associated with anthropogenic influences.

Background Information:
This species is primarily found in harbors and attached to artificial structures (Pérez-Portela et al. 2013). Modelling exercises suggest that D. listerianum is resilient to local and regional disturbances (Munguia et al. 2010), and that disturbance may actually increase its spread (Altman and Whitlatch 2007). Anthropogenic development of coastal areas may promote Diplosoma-dominated communities (Osman et al. 2010).

Sources:
Pérez-Portela et al. 2013   Munguia et al. 2010   Altman and Whitlatch 2007   Osman et al. 2010

2.3 Is this species currently or potentially farmed or otherwise intentionally cultivated?

Choice: **B**

No

Score: 0 of 2

Ranking Rationale:

Background Information:
D. listerianum is not currently farmed or cultivated.

Sources:
None listed

Section Total - Scored Points:	6.75
Section Total - Possible Points:	10
Section Total -Data Deficient Points:	0

3. Biological Characteristics

3.1 Dietary specialization

Choice: **A** — Generalist at all life stages and/or foods are readily available in the study area

Score: 5 of 5

Ranking Rationale:
Phytoplankton is an abundant food source in the Bering Sea.

Background Information:
D. listerianum is a suspension feeder that eats phytoplankton. The larval stage is non-feeding.

Sources:
NEMESIS; Fofonoff et al. 2003   Pérez-Portela et al. 2013

3.2 Habitat specialization and water tolerances

Does the species use a variety of habitats or tolerate a wide range of temperatures, salinity regimes, dissolved oxygen levels, calcium concentrations, hydrodynamics, pollution, etc?

Choice: **A** — Generalist; wide range of habitat tolerances at all life stages

Score: 5 of 5

Ranking Rationale:
Tolerant of a wide range of temperatures and salinities.

Background Information:
Tolerates a wide range of temperatures and salinity regimes, although its ability to tolerate brackish waters may be limited or require acclimation (Fofonoff et al. 2003; Gröner et al. 2011). A field experiment by Dijkstra et al. (2007a) found that D. listerianum grew on panels placed in both fouling and natural (benthic) habitats, and grew on all panel types (panels varied in terms of orientation and water depth).

Sources:
NEMESIS; Fofonoff et al. 2003   Dijkstra et al. 2007a   Gröner et al. 2011

3.3 Desiccation tolerance

Choice: **C** — Little to no tolerance (<1 day) of desiccation during its life cycle

Score: 1.75 of 5

High uncertainty? ☑

Ranking Rationale:

Background Information:
Tunicates in general have little to no desiccation tolerance (Pleus et al. 2008).

Sources:
Pleus et al. 2008

3.4 *Likelihood of success for reproductive strategy*

i. Asexual or hermaphroditic   ii. High fecundity (e.g. >10,000 eggs/kg)   iii. Low parental investment and/or external fertilization   iv. Short generation time

Choice: **A** High – Exhibits three or four of the above characteristics

Score: 5 of 5

Ranking Rationale:

Asexual reproduction, high fecundity, low parental investment, short generation time.

Background Information:

D. listerianum has both sexual and asexual reproduction. Asexual reproduction occurs through budding, and produces colonies of genetically identical zooids. Zooids are hermaphroditic. Sperm are released externally, but fertilization is internal. Populations can have between 1 to 3 generations per year, and can produce larvae in 2-4 weeks after settlement (Millar 1954, qtd. in Fofonoff et al. 2003). The complete life cycle from settlement to death ranged from 12 to 18 months (Millar 1952, qtd. in Mackenzie 2011). Fertilization can occur even with low levels of sperm concentrations (Bishop 1998).

Sources:

NEMESIS; Fofonoff et al. 2003   Bishop 1998   Dijkstra 2009   Mackenzie 2011

3.5 *Likelihood of long-distance dispersal or movements*

Consider dispersal by more than one method and/or numerous opportunities for long or short distance dispersal e.g. broadcast, float, swim, carried in currents; vs. sessile or sink.

Choice: **C** Disperses short (< 1 km) distances

High uncertainty? ☑

Score: 0.75 of 2.5

Ranking Rationale:

Information is lacking, but this species probably has limited natural dispersal potential given its short-lived larval stage and sessile adult life.

Background Information:

Several sources agree that D. listerianum has limited dispersal potential (Munguia et al. 2010; Munguia et al. 2011; Pérez-Portela et al. 2013). Adults are sessile, but creeping movements are possible (Sommerfeldt and Bishop 1999). Rafting on macroalgae and debris may transport colonies both long and short distances (Thiel and Gutow 2005). Free-swimming larval stage lasts only a few hours (<24 h). Marshall et al. (2003) found that delaying metamorphosis by 3 to 6 h had strong negative effects on post-metamorphic growth. Similarly, short (<3 h) periods of larval swimming depleted energy reserves by almost 25%; the high cost of active swimming may limit larval dispersal (Bennett and Marshall 2005).

Sources:

Dijkstra 2009   Bennet and Marshall 2005   Sommerfeldt and Bishop 1999   Munguia et al. 2011   Marshall et al. 2003   Pérez-Portela et al. 2013   Munguia et al. 2010   Thiel and Gutow 2005

3.6 Likelihood of dispersal or movement events during multiple life stages

i. Can disperse at more than one life stage and/or highly mobile ii. Larval viability window is long (days v. hours) iii. Different modes of dispersal are achieved at different life stages (e.g. unintentional spread of eggs, migration of adults)

Choice: **C** Low – Exhibits none of the above characteristics

Score: 0.75 of 2.5

Ranking Rationale:
Active dispersal is only possible during short-lived larval stage. Eggs are brooded internally and adults are mostly sessile.

Background Information:
Sperm is viable for several hours (up to 24 hours; Bishop 1998), and sperm can be retained in oviducts for weeks (Pérez-Portela et al. 2013). Eggs are fertilized internally and brooded until ready to be released as larvae. Larvae are capable of free-swimming, but short-lived (< 24 hours). Adults are largely sessile, but natural dispersal of fragments (e.g. by rafting on kelp) is possible (Thiel and Gutow 2005).

Sources:
Bishop 1998 Thiel and Gutow 2005 Pérez-Portela et al. 2013

3.7 Vulnerability to predators

Choice: **D** Multiple predators present in the Bering Sea or neighboring regions

Score: 1.25 of 5

Ranking Rationale:
Numerous predators, many of which exist in the Bering Sea or nearby ecoregions.

Background Information:
In its introduced range, D. listerianum is preyed upon by several species, including snails (Mitrella lunata and Anachis lafrashnayi), blood stars (Henricia sanguinolenta), European green crab (Carcinus maenas), Japanese shore crab (Hemigrapsus sanguineus), portly spider crab (Libinia emarginata), Cunner (Tautogolabrus adspersus), lunar dovesnail (Astyris lunata), and well-ribbed dovesnail (Anachis lafresnayi) (Osman and Whitlatch 1995; Harris and Tyrrell 2001; Osman and Whitlatch 2004; Altman and Whitlatch 2007; Dijkstra et al. 2007a).

Sources:
Dijkstra 2009 Dijkstra et al. 2007a Altman and Whitlatch 2007 Harris and Tyrrell 2001 Osman and Whitlatch 1995 Osman and Whitlatch 2004 Mackenzie 2011

Section Total - Scored Points:	19.5
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

4. Ecological and Socioeconomic Impacts

4.1 Impact on community composition

Choice: C Limited – Single trophic level; may cause decline but not extirpation

Score: 0.75 of 2.5

Ranking Rationale:
Can outcompete native species, especially on hard substrates.

Background Information:
In Long Island Sound, D. listerianum caused reduced recruitment for polychaetes (Spirorbis spp.), barnacles (Balanus spp.), and bryozoans (Bugula spp., Botryllus schlosseri, Botrylloides violaceus) (Osman and Whitlatch 1995). D. listerianum overgrows other fouling organisms on plates and panels, and few species are able to resist the overgrowth (Schmidt and Warner 1986; Agius 2007; Vance et al. 2009). When growing on algae, D. listerianum may block off light and prevent nutrient absorption (Harris and Tyrrell 2001).

Sources:
Agius 2007   Harris and Tyrrell 2001   Mackenzie 2011   Vance et al. 2009   NEMESIS; Fofonoff et al. 2003   Osman and Whitlatch 1995   Schmidt and Warner 1986

4.2 Impact on habitat for other species

Choice: D No impact

Score: 0 of 2.5

Ranking Rationale:
To date, no impacts on habitat for other species have been reported.

Background Information:
No information available in the literature.

Sources:
None listed

4.3 Impact on ecosystem function and processes

Choice: D No impact

Score: 0 of 2.5

Ranking Rationale:
To date, no impacts on ecosystem function or processes have been reported, and given its ecology, none is expected.

Background Information:
No information available in the literature.

Sources:
None listed

4.4 Impact on high-value, rare, or sensitive species and/or communities

Choice: D No impact

Score: 0 of 2.5

Ranking Rationale:
To date, no impacts on high-value, rare, or sensitive species have been reported.

Background Information:
No information available in the literature.

Sources:
None listed

4.5 Introduction of diseases, parasites, or travelers

What level of impact could the species' associated diseases, parasites, or travelers have on other species in the assessment area? Is it a host and/or vector for recognized pests or pathogens, particularly other nonnative organisms?)

Choice: C Limited – Has limited potential to spread one or more organisms, with limited impact and/or within a very limited region

Score: 0.75 of 2.5

High uncertainty? ☑

Ranking Rationale:

Background Information:
Little is known about diseases affecting, or caused by, tunicates. There are records of copepods living parasitically inside ascidians (Ooishi 1998, qtd. in Mackenzie 2011).

Sources:
Mackenzie 2011

4.6 Level of genetic impact on native species

Can this invasive species hybridize with native species?

Choice: D No impact

Score: 0 of 2.5

Ranking Rationale:
To date, no impacts on genetics of native species have been reported.

Background Information:
No information available in the literature.

Sources:
None listed

4.7 Infrastructure

Choice: B Moderate – Causes or has the potential to cause degradation to infrastructure, with moderate impact and/or within only a portion of the region

Score: 1.5 of 3

High uncertainty? ☑

Ranking Rationale:
Moderate impacts on infrastructure are expected given its abundance as a fouling organism.

Background Information:
Abundant fouling organism on boats, marinas, buoys, floats, and other manmade structures (Lambert 2002). Fouling organisms on ships cause drag, reduce maneuverability, and increase fuel costs. It is estimated that hull fouling organisms cost the U.S. Navy over $50 million a year in fuel due to increased drag (Cleere 2001).

Sources:
NEMESIS; Fofonoff et al. 2003   Lambert 2002   Cleere 2001

4.8 Commercial fisheries and aquaculture

Choice: C — Limited – Has limited potential to cause degradation to fisheries and aquaculture, and/or is restricted to a limited region

Score: 0.75 of 3

High uncertainty? ✔

Ranking Rationale:
Known to foul cultivated shellfish, but its effects on shellfish are unknown.

Background Information:
D. listerianum has been reported fouling cultured shellfish in Brazil, United Kingdom, Croatia, Japan, and Hong Kong (Ross et al. 2004; Igic 1972; Arakawa 1990; Huang 2003 qtd. in Rocha et al. 2009). Colonies usually stop growing at the margin of the bivalve shells, and since it is very thin it is probably harmless to bivalve growth, but no studies have tested this hypothesis (Rocha et al. 2009).

The shellfish industry in Alaska is estimated at $1 million (Pacific Shellfish Institute). Aquaculture is important in the Gulf of Alaska, but only occurs in a limited portion of the Bering Sea (Mathis et al. 2015).

Sources:
NEMESIS; Fofonoff et al. 2003   Rocha et al. 2009   Mathis et al. 2015   PSI Alaska 2017

4.9 Subsistence

Choice: C — Limited – Has limited potential to cause degradation to subsistence resources, with limited impact and/or within a very limited region

Score: 0.75 of 3

High uncertainty? ✔

Ranking Rationale:
Known to foul cultivated shellfish, but its effects on shellfish and on subsistence harvesting are unknown.

Background Information:
The effects of D. listerianum on shellfish are unknown. In most municipalities of the Bering Sea, shellfish such as oysters, clams, and mussels comprise a small percentage of subsistence catch (< 5% when measured by weight, except for the Western Aleutians; Mathis et al. 2015).

Sources:
Mathis et al. 2015

4.101 Recreation

Choice: C — Limited – Has limited potential to cause degradation to recreation opportunities, with limited impact and/or within a very limited region

Score: 0.75 of 3

High uncertainty? ✔

Ranking Rationale:
Although this species fouls shellfish species, the effects of this fouling are unknown. Recreational harvesting of shellfish in the Bering Sea is limited.

Background Information:
No information found.

Sources:
None listed

4.11 Human health and water quality

Choice: **D** No impact

Score: **0** **of** **3**

Ranking Rationale:
To date, no impacts on human health or water quality have been reported for D. listerianum, and given its ecology, none would be expected.

Background Information:
No information available in the literature.

Sources:
None listed

Section Total - Scored Points:	5.25
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

5. Feasibility of prevention, detection and control

5.1 History of management, containment, and eradication

Choice: **C** Attempted; control methods are currently in development/being studied

Score: of

Ranking Rationale:
Methods to control tunicates are being studied.

Background Information:
Attempts to control invasive tunicates are ongoing (Carman et al. 2016). Several control methods are being tested and include high-pressure washing and cleaning with brine, freshwater or lime solutions (DFO 2010; Carman et al. 2016).

Sources:
DFO 2010 Carman et al. 2016

5.2 Cost and methods of management, containment, and eradication

Choice: **B** Major short-term and/or moderate long-term investment

Score: of

Ranking Rationale:
Current methods to control tunicates require repeated treatments at moderate costs.

Background Information:
In PEI, chemical and water (brine and freshwater) treatments are applied to mussel socks to control fouling tunicates such as D. listerianum (Carman et al. 2016). Tunicates recolonized treated socks; repeated treatments are therefore required (Carman et al. 2016).

Sources:
Carman et al. 2016

5.3 Regulatory barriers to prevent introductions and transport

Choice: **A** Little to no regulatory restrictions

Score: of

Ranking Rationale:
No species-specific regulations, but monitoring programs exist for invasive aquatic species.

Background Information:
Monitoring programs in New England and Canada are in place for detecting aquatic invasive species. These monitoring programs were responsible for early detection of D. listerianum in Quebec (Ma et al. 2016). In the Pacific Northwest, no regional organizations are currently tracking D. listerianum (Curran 2013). This species can be transported by hull fouling; compliance with fouling regulations is largely voluntary in the U.S. (Hagan et al. 2014).

Sources:
Curran 2013 Ma et al. 2016 Hagan et al. 2014

5.4 *Presence and frequency of monitoring programs*

Choice: **B** — Surveillance takes place, but is largely conducted by non-governmental environmental organizations (e.g., citizen science programs)

Score: of

Ranking Rationale:
D. listerianum is monitored by volunteers from the Invasive Tunicate Network and KBNERR.

Background Information:
In Alaska, the Invasive Tunicate Network and KBNERR conduct monitoring for non-native tunicates and other invasive or harmful species. The programs involve teachers, students, outdoor enthusiasts, environmental groups and professional biologists to detect invasive species.

Sources:
iTunicate Plate Watch 2016

5.5 *Current efforts for outreach and education*

Choice: **D** — Programs and materials exist and are readily available in the Bering Sea or adjacent regions

Score: of

Ranking Rationale:
Several programs in Alaska and Canada have training and educational materials for D. listerianum.

Background Information:
Alaska’s Invasive Tunicate Network and the Kachemak Bay National Estuarine Research Reserve (KBNERR) provide training opportunities for identifying and detecting non-native tunicates, and public education events on coastal and marine ecosystems more generally. Southeast AK hosts an annual Marine Invasive Species Bioblitz, which engages the public through education and hands-on activities. Field identification guides for native and non-native tunicates, as well as common fouling organisms, are readily available. PEI Aquaculture Alliance and Salem Sound Coastwatch provide identification cards on their website. Also listed in the Aquatic Invasive Species identification booklet prepared by Fisheries and Oceans Canada.

Sources:
iTunicate Plate Watch 2016   FOC 2016   PEIAA 2016

Section Total - Scored Points:

Section Total - Possible Points:

Section Total -Data Deficient Points:

Literature Cited for *Diplosoma listerianum*

- Carman, M. R., Lindell, S., Green-Beach, E., and V. R. Starczak. 2016. Treatments to eradicate invasive tunicate fouling from blue mussel seed and aquaculture socks. Management of Biological Invasions 7(1):101-110.
- Cleere, G. 2001. Battling the barnacle (and other ship-fouling critters). 2001 Media Releases, Office of Naval Research, Arlington, VA. Available from: https://www.onr.navy.mil/en/Media-Center/Press-Releases/2001/Battling-the-Barnacle.aspx Accessed 11-Jan
- Curran, L. 2013. Invasive Tunicates in the Pacific Northwest. Oregon State University, Corvallis, OR, U.S.A. 32 pp.
- Hagan, P., Price, E., and D. King. 2014. Status of vessel biofouling regulations and compliance technologies – 2014. Maritime Environmental Resource Center (MERC) Economic Discussion Paper 14-HF-01.
- Mathis, J. T., Cooley, S. R., Lucey, N., Colt, S., Ekstrom, J., Hurst, T., Hauri, C., Evans, W., Cross, J. N., and R. A. Feely. 2015. Ocean acidification risk assessment for Alaska’s fishery sector. Progress in Oceanography 136:71–91. doi: 10.1016/j.poce
- Fofonoff, P. W., G. M. Ruiz, B. Steves, C. Simkanin, and J. T. Carlton. 2017. National Exotic Marine and Estuarine Species Information System. http://invasions.si.edu/nemesis/. Accessed: 15-Sep-2017.
- Osman, R. W., Munguia, P., Whitlatch, R. B., Zajac, R. N., and J. Hamilton. 2010. Thresholds and multiple community states in marine fouling communities: integrating natural history with management strategies. Marine Ecology Progress Series 413:277–289.
- Pérez-Portela, R., Arranz, V., Rius, M., and X. Turon. 2013. Cryptic speciation or global spread? The case of a cosmopolitan marine invertebrate with limited dispersal capabilities. Scientific Reports 3: 3197.
- Bishop, J. D. D. 1998. Fertilization in the sea: are the hazards of broadcast spawning avoided when free–spawned sperm fertilize retained eggs? Proceedings of the Royal Society B 265(1397): 725-731. *Access to abstract only.
- Dijkstra, J. 2009. Diplosoma listerianum. CABI Invasive Species Compendium. Available from: http://www.cabi.org/isc/datasheet/109099. Accessed 30-Nov-2016.
- Mackenzie, A. B. 2011. Biological synopsis of the compound sea squirt (Diplosoma listerianum). Canadian Manuscript Report of Fisheries and Aquatic Sciences no. 2966. Fisheries and Oceans Canada, Centre of Expertise for Aquatic Risk Assessment, Burlington,
- Bennett, C. E., and D. J. Marshall. 2005. The relative energetic costs of the larval period, larval swimming and metamorphosis for the ascidian Diplosoma listerianum. Marine and Freshwater Behaviour and Physiology 38(1): 21–29.
- Marshall, D. J., Pechenik, J. A., and M. J. Keough. 2003. Larval activity levels and delayed metamorphosis affect post-larval performance in the colonial ascidian Diplosoma listerianum. Marine Ecology Progress Series 246:153–162.
- Rocha, R. M., Kremer, L. P., Baptista, M. S., and R. Metri. 2009. Bivalve cultures provide habitat for exotic tunicates in southern Brazil. Aquatic Invasions 4(1): 195-205.
- Carman, M.R., Lindell, S., Green-Beach, E., and V.R. Starczak. 2016. Treatments to eradicate invasive tunicate fouling from blue mussel seed and aquaculture socks. Management of Biological Invasions 7(1): 101–110.
- Curran, L. 2013. Invasive Tunicates in the Pacific Northwest. Oregon State University. Accessed 12/01/2016.
- Ma, K. C. K., Simard, N., Stewart-Clark, S .E., Bernier, R. Y., Nadeau, M., and J. Willis. 2016. Early detection of the non-indigenous colonial ascidian Diplosoma listerianum in eastern Canada and its implications for monitoring. Management of Biological

- Fisheries and Oceans Canada. 2016. Aquatic Invasive Species Identification Booklet. Available from: http://waves-vagues.dfo-mpo.gc.ca/Library/365586.pdf Accessed 01-Dec-2016.
- PEIAA. 2016. Diplosoma tunicate (Diplosoma listerianum). Prince Edward Island Aquaculture Alliance. Available from: http://www.aquaticintruders.com/species/Diplosoma-listerianum Accessed 01-Dec-2016.
- Zerebecki, R. A., and C. J. B. Sorte. 2011. Temperature tolerance and stress proteins as mechanisms of invasive species success. PLoS ONE 6: e14806.
- Sorte, C. J. B., Jones, S. J., and L. P. Miller. 2011. Geographic variation in temperature tolerance as an indicator of potential population responses to climate change. Journal of Experimental Marine Biology and Ecology 400:209–217. doi: 10.1016/j.jembe.
- iTunicate Plate Watch. 2016. Available from: http://platewatch.nisbase.org
- PSI Alaska. 2017. Alaska Mariculture Initiative: Economic Analysis to Inform a Statewide Strategic Plan. Pacific Shellfish Institute. Available from: http://www.pacshell.org/AKprojects.asp Accessed 28-Feb-2017.
- Osman, R. W., and R. B. Whitlatch. 1995. The influence of resident adults on recruitment: A comparison to settlement. Journal of Experimental Marine Biology and Ecology 190:169-198.
- Carman, M.R., Lindell, S., Green-Beach, E., and V.R. Starczak. 2016. Treatments to eradicate invasive tunicate fouling from blue mussel seed and aquaculture socks. Management of Biological Invasions 7(1): 101-110.
- Lord, J. P. 2017a. Temperature, space availability, and species assemblages impact competition in global fouling communities. Biological Invasions 19:43–55.
- Wyatt, A. S., Hewitt, C. L., Walker, D. I., and T. J. Ward. 2005. Marine introductions in the Shark Bay World Heritage Property, Western Australia: A preliminary assessment. Diversity and Distributions 11:33-44.
- Vance, T., Lauterback, L., Lenz, M., Wahl, M., Sanderson, R. A., and J. C. Thomason. 2009. Rapid invasion and ecological interactions of Diplosoma listerianum in the North Sea, UK. Marine Biodiversity Records 2: e59. doi: 10.1017/S1755267209000815
- Munguia, P., Osman, R. W., Hamilton, J., Whitlach, R. B., and R. N. Zajac. 2010. Modeling of priority effects and species dominance in Long Island Sound benthic communities. Marine Ecology Progress Series 413:229-240.
- Altman, S., and R. B. Whitlatch. 2007. Effects of small-scale disturbance on invasion success in marine communities. Journal of Experimental Marine Biology and Ecology 342:15-29.
- Dijkstra, J., Harris, L. G., and E. Westerman. 2007a. Distribution and long-term temporal patterns of four invasive colonial ascidians in the Gulf of Maine. Journal of Experimental Marine Biology and Ecology 342:61-68.
- Harris, L. G., and M. C. Tyrrell. 2001. Changing community states in the Gulf of Maine: Synergism between invaders, overfishing and climate change. Biological Invasions 3: 9-21.
- Osman, R. W., and R. B. Whitlatch. 2004. The control of the development of a marine benthic community by predation on recruits. Journal of Experimental Marine Biology and Ecology 311:117-145.
- Sommerfeldt, A. D., and J. D. D. Bishop. 1999. Random amplified polymorphic DNA (RAPD) analysis reveals extensive natural chimerism in a marine protochordate. Molecular Ecology 8:885-890.
- Munguia, P., Osman, R. W., Hamilton, J., Whitlatch, R. B., and R. Zajac. 2011. Changes in habitat heterogeneity alter marine sessile benthic communities. Ecological Applications 21(3):925-935.

- Marshall, D. J., Pechenik, J. A., Keough, M. J. (2003). Larval activity levels and delayed metamorphosis affect post-larval performance in the colonial ascidian Diplosoma listerianum. Marine Eoclogy Progress Series, 246, 153-162.
- Agius, B. P. 2007. Spatial and temporal effects of pre-seeding plates with invasive ascidians: Growth, recruitment and community composition. Journal of Experimental Marine Biology and Ecology 342: 30-39.
- Schmidt, G. H., and G. F. Warner. 1986. Spatial competition between colonial ascidians: The importance of stand-off. Marine Ecology Progress Series 31:101-104.
- Lambert, G. 2002. Nonindigenous Ascidians in Tropical Waters. Pacific Science 56(3):291-298.
- Gittenberger, A. 2007. Recent population expansions of non-native ascidians in The Netherlands. Journal of Experimental Marine Biology and Ecology 342:122-126.
- DFO. 2010. Containment and mitigation of nuisance tunicates on Prince Edward Island to improve mussel farm productivity. Aquaculture Collaborative Research and Development Program Fact Sheet. Aquaculture Science Branch, Fisheries and Oceans Canada, Ottawa
- Lord, J. P. 2017b. Impact of seawater temperature on growth and recruitment of invasive fouling species at the global scale. Marine Ecology 38:1–10. doi:10.1111/maec.12404
- Gröner F., Lenz M., Wahl M., and S. R. Jenkins. 2011. Stress resistance in two colonial ascidians from the Irish Sea: The recent invader Didemnum vexillum is more tolerant to low salinity than the cosmopolitan Diplosoma listerianum. Journal of Experimenta
- Ryland, J., and J. Bishop. 1990. Prevalence of cross-fertilization in the hermaphroditic compound ascidian Diplosoma listerianum. Marine Ecology Progress Series 61:125–132. doi: 10.3354/meps061125
- Stachowicz, J. J., Terwin, J. R., Whitlatch, R. B., and R. W. Osman. 2002. Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. PNAS 99:15497–500. doi: 10.1073/pnas.242437499
- Thiel, M., and L. Gutow. 2005. The ecology of rafting in the marine environment. II. The rafting organisms and community. Oceanography and Marine Biology An Annual Review 43:279–418. doi: 10.1201/9781420037449.ch7
- Lord, J. P., Calini, J.M., and R. B. Whitlatch. 2015. Influence of seawater temperature and shipping on the spread and establishment of marine fouling species. Marine Biology 162:2481–2492. doi:10.1007/s00227-015-2737-2