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Invasive Estuarine and Marine Animals of the North Atlantic

by Gary L. Ray

PURPOSE: New species of estuarine and marine animals are inadvertently or intentionally introduced into the waters of the United States every year (Figure 1). Variously referred to as introduced, nonindigenous (NIS), alien, nonnative, or exotic species, most pose little or no threat; however, a few have the potential to disrupt local ecosystems, fisheries, and human infrastructure. Such invasions directly impact the mission of the U.S. Army Corps of Engineers (USACE) through its responsibilities for construction and maintenance of harbors, ports, and waterways; erosion control; management of water resources; and wetland and coastal habitat restoration. The general biology and ecology of invasive estuarine and marine animals have been described in previous reports (e.g., Carlton (2001), Ray (2005)). This report is part of a series describing the biology and ecology of known invasive estuarine and marine animals in the major geographic regions of the United States. Invasive animals of the North Atlantic region are described and examples of species posing a specific threat to USACE activities are identified.

BACKGROUND: Invasive species are officially defined as "alien species whose introduction does or is likely to cause economic or environmental harm to human health" (Executive Order 13112, Federal Register (1999)). Any species removed from its native range has the potential to become invasive. Within a species' normal range, predation, disease, parasites, competition, and other natural controls act to keep population levels in check (Torchin et al. 2003, Wolfe 2002). Once released from these controls, species abundances have the potential to reach levels that interfere with or displace local fauna. Such effects may occur immediately, after some period of delay, or may never be realized at all depending on the characteristics of the individual species and the conditions into which it is introduced.

Figure 1. Example of an invasive species, the Japanese Shore Crab, *Hemigrapsus sanguineus* (image courtesy of USGS)

Lists of estuarine and marine nonindigenous species are often dominated by mollusks, crustaceans, and polychaete worms; however, this may reflect their ease of identification and detection rather than the degree to which they are representative. Ultimately, it is an issue of an organism's biological characteristics (e.g., reproductive capacity, growth rate, etc.) and not its taxonomic affinities that determine if it becomes invasive. Successful invaders tend to be those that are abundant over a large range in their native region, have broad feeding and habitat preferences, wide

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physiological tolerances, short generation times, and high genetic variability (Erlich 1989, Williams and Meffe 1999). Despite the fact that we can identify these characteristics, predicting which species pose the greatest threat remains problematic. While many species possess these characters, most are not obvious in their native range, and the opportunity to be introduced and subsequent likelihood of survival are difficult to assess. The situation is further complicated by difficulty in distinguishing invaders from species with naturally wide distributions and those that are cryptogenic, that is, species whose original distributions are uncertain.

Predicting which habitats are likely to be invaded is much simpler. Invaded habitats tend to have low natural diversity, relatively simple (low-connectance) food webs, and a history of recent natural or anthropogenic disturbance (Williams and Meffe 1999). Estuaries and sheltered coastal areas are among the most invaded habitats, presumably due to the fact that they are naturally disturbed, low-diversity systems, and are historically centers of anthropogenic disturbance associated with navigation, industrial development, and urbanization.

Species are introduced by a variety of different mechanisms; however, most estuarine and marine species introductions are associated with shipping (Ruiz et al. 2000). Species capable of attaching to hard surfaces may be transported on ship hulls, navigational buoys, floatation devices, anchors, chains, ropes, and flotsam or jetsam (Carlton 2001). During the heyday of wooden-hulled ships, wood borers (e.g., shipworms) and species associated with "dry" ballast such as stones, rock, sand, or other materials were frequently introduced (Carlton and Hodder 1995). Presently, the largest single source of shipping-related introductions is ballast water (Carlton 1985, Lavoie et al. 1999). Ballast water is taken onboard vessels for a variety of purposes related to ship maneuverability and control (Carlton et al. 1995). Animals suspended in the water column or present in bottom sediments are taken in and then introduced to a new location when the ballast is pumped out.

Recently, concerns have also been raised regarding introductions of fish, invertebrates, and "live" rock from the aquarium trade (Padilla and Williams 2004, Weigle et al. 2005). The lionfish *Pterois volitans* may have been introduced when a private aquarium was demolished in the Miami area during Hurricane Andrew in 1992 (Hare and Whitfield 2003). Other introductions may result from accidental release of animals, inappropriate disposal of packing material by restaurants serving live seafood, and by the live bait industry. Many species have been deliberately introduced to develop new fisheries. For example, the Atlantic Striped Bass (*Morone* saxatilis) has been introduced both outside its normal geographic range and in non-native habitats (e.g., reservoirs) in much of the United States.

METHODS: As indicated in the official definition, invasive species are nonindigenous or alien to the region in which they are found. This does not mean that all NIS are invasive but rather that invasives constitute a subset of NIS. For the purposes of this report, the North Atlantic region is defined as covering the geographic area between the state of Maine and Chesapeake Bay. In order to create a list of known invasive species within this region, NISBase, a national database of NIS listings maintained by the Smithsonian Institution (*http://www.nisbase.org/nisbase/index.jsp*) was queried. Part of the National Exotic Marine and Estuarine Species Information System (NEMESIS), the database permits simultaneous searches of multiple NIS listings. Searches return up to 300 species and include links to individual species' fact sheets and collection data. Queries were performed by state and included searches of the United States Geological Survey's Nuisance Aquatic Species (NAS) database (*http://nas.er.usgs.gov/*) and the Chesapeake Bay Exotic Marine and Estuarine Species Information System database. The resulting lists were amended as necessary after comparison with individual state NIS listings and other reports (Table 1), then edited to include only estuarine and marine species (Appendix A). Cryptogenic species were excluded from consideration due to the uncertainty of their origins. Only species known to be invasive or possessing the potential to become invasive are discussed.

Table 1
State NIS Listings and Other Sources Utilized in This Report

Benson and Richerson 2004
Benson et al. 2004
Carlton 2004
Massachusetts Aquatic Invasive Species Working Group 2002
Massachusetts Institute of Technology 2004
New York Sea Grant 2001
State of Vermont 2004

RESULTS: NIS listings for the North Atlantic region include 122 estuarine and marine animal species (Table 2). Not surprisingly, the greatest number of species was found among the molluscs (25 species) and fishes (19 species). Many of these represent species that were deliberately introduced, such as the oysters *Crassostrea gigas*, *C. ariakensis*, and *Ostrea edulis*, the Japanese littleneck clam *Venerupis phillippinarum*, and fish including five species of west coast salmon

Table 2
Summary Results for Numbers of North Atlantic NIS by State

Taxon	ME	MA	NH	VE	RI	CN	NY	NJ	PA	DE	MD	VA	Total for Region
Protozoans		2						2			2	2	3
Sponges	1	2			1	1	1						2
Jellyfish											2	3	4
Anemones	1	2									1	2	3
Hydrozoans	2	1											2
Platyhelminths	1												1
Oligochaetes												1	1
Polychaetes	2				1						2	5	7
Bivalves	2	8			1	1	3	2			5	8	12
Gastropods	1	2			1			1		1	3	8	9
Nudibranchs	1	4										2	4
Copepods		1					1				2	2	3
Barnacles		3			1		1	1			2	2	5
Amphipods	2	3			1	1					1	6	10
Isopods	2	1						2			1	2	6
Mysids	1	1									1	1	2
Crabs	2	2	2		2	2	2	2		2	2	2	2
Insects	1	1									2	2	5
Bryozoans	6	7			1	1						1	8
Kamptozoans		1									2	2	3
Tunicates	4	11	3		5	4	1			1	1	9	12
Fish	4	8	3	7		4	11	4	14	4	9	10	19
Total	33	61	8	7	14	14	20	14	14	8	38	70	122

(*Onchorhynchus spp.*). A large number of indigenous fish are also included because they were stocked in so-called nonindigenous waters, i.e., waters where they don't naturally occur. These fish include all five species of shad and herring (*Alosa aestivalis, A. pseudoharengus, A. sapidissima, Dorosoma cepedianum*, and *D. petenense*), the mummichog *Fundulus heteroclitus,* the Atlantic cod *Gadus morhua,* the Atlantic salmon *Salmo salar,* and the striped bass *Morone saxatilis*. Several species may have been unintentionally introduced during shellfish introductions, including the oyster-disease-causing protozoans *Haplosporidium nelsoni* and *Perkinsus marinus* and the Japanese oyster drill *Eupleura sulcidentata*. The virus *Bonamia ostea,* also fatal to oysters, is believed to have entered New England waters during shellfish introductions. Taken together, nearly 20 percent of all listed NIS in the North Atlantic are directly or indirectly attributable to deliberate introduction.

Fortunately, most of the fish introductions were of limited success and probably represent no direct threat to USACE operations. The unintentional introduction of the oyster diseases and predators, however, poses continuing difficulties to restoration of oyster habitat and stocks throughout the region.

An additional 37 NIS species (30 percent) are associated with hard structures and may contribute to fouling. Presumably introduced on ships' hulls or ballast water, they include two sponges (porifera), two hydrozoans, three anemones, five barnacles, eight bryozoans, three kamptozoans (entoprocts), twelve tunicates, and two polychaetes (Appendix A).

Distribution of NIS species among individual states varies widely, and to some degree, is a function of the amount of coastline and the intensity of efforts to detect NIS species (Table 1). Maine, Massachusetts, Maryland, and Virginia have extensive coastlines, a history of NIS monitoring, and the greatest numbers of recorded NIS species, while New Hampshire and Vermont with their relatively small coastlines have the fewest. For a review of factors potentially affecting the level of knowledge regarding NIS distributions and abundance, see Ray (2005).

DISCUSSION: Species most commonly identified as invasive or listed as of concern in North Atlantic states are the European green crab *Carcinus maenas*, the Japanese shore crab *Hemigrapsus sanguineus* (Figure 1), the white lace bryozoan *Membranipora membrancea,* the tunicates *Styella clavata* and *Botrylloides diagensis,* and the lionfish *Pterois volitans*. With the exception of the Japanese shore crab, the biology and potential impacts on USACE operations of these species have previously been described in Ray (2005).

Potential Threats to Infrastructure. The primary threat to infrastructure comes from several species of *Teredo* spp., wood-boring bivalve molluscs commonly called shipworms. Most shipworms, including the native species *Bankia gouldii*, are tolerant of a wide range of salinities and temperatures and low oxygen conditions. Shipworms are a potentially serious threat to wooden structures including boats, marinas, docks, and pilings. Cohen and Carlton (1995) report that a shipworm outbreak in San Francisco Bay resulted in $615 million in damage during the 1920's. Likewise, severe damage was reported in Barnegat Bay, New Jersey and Long Island Sound, New York following outbreaks of *T. bartschi* associated with increased water temperatures and salinities in power station effluents (Hoagland 1983). These pests can be effectively controlled by chemical treatment (e.g., creosote) of wood or use of alternative materials (Highley 1999).

Because of their ability to foul coastal structures such as intake pipes, a variety of introduced fouling species (e.g., sponges, barnacles) have the potential to interfere with USACE operations. Thus far, only the hydroids *Cordylophora caspia* and *Garveia franciscana* have been positively identified as posing such a threat (Massachusetts Institute of Technology 2004). The tunicate *Didemnum lahille* has recently interfered indirectly with a navigation project. This species is undergoing a major outbreak in New England (National Marine Fisheries Northeast Science Center 2004) and resource agencies have voiced the concern that dredging operations might contribute to its spread.[1]

Potential Threats to Habitat Restoration. Green crabs feed voraciously on shellfish and may disrupt attempts to restore softshell clam (*Mya arenaria*) stocks. Another species that may affect shellfish restoration is the whelk *Rapana venosa* (Figure 2). Presently limited to Chesapeake Bay, it is likely to expand its range to include most of the North Atlantic and portions of the South Atlantic (Mann and Harding 2003). This species is a voracious predator of shellfish, including hard clams (*Mercenaria mercenaria*), softshell clams, and oysters. Control efforts currently include offering a bounty for whelks and encouraging local restaurants to develop recipes incorporating this species.

Figure 2. The Veined Rapa Whelk, *Rapana venosa* (image courtesy of the Jacksonville Florida Shell Club)

Japanese shore crab. The Japanese shore crab is a native of the western Pacific Ocean characteristically found in low intertidal and subtidal zones with rock or cobble substrates. First detected in New Jersey in 1988 (McDermott 1991), it has since spread north into southern New England (Lohrer and Whitlach 1997) and south into Chesapeake Bay. It has quickly become one of the most abundant crabs in the rocky intertidal zone, displacing native xanthid crabs and even the invasive green crab from areas where their distributions overlap (Lohrer and Whitlach 1997, Jensen et al. 2002). It has an extended breeding season and tolerates salinities as low as 15 ppt as larvae (Epifaunio et al. 1998). Adults appear to prefer salinities of 20 ppt or higher. The Japanese shore crab has broad food preferences including macroalgae, snails, mussels, and barnacles (Lohrer and Whitlach 1997, Bourdeau and O'Connor 1999, Percival and Wilson 2001). While it seems doubtful this species will directly interfere with USACE operations, the issue of incidentally contributing to its spread has arisen in situations where riprap or other coarse materials are being placed in the intertidal zone[2]. Since there are presently no known control methods, the issue remains problematic.

[1] Personal communication, 2004, Catherine Rogers, Ecologist, U.S. Army Engineer District, New England, Concord, MA.
[2] Personal communication, 2004, Robert Will, U.S. Army Engineer District, New York.

European periwinkle. An additional species of concern in northern New England is the common or European periwinkle *Littorina littorea*. Introduced sometime in the mid-19th century, it has spread throughout the North Atlantic region. It has displaced native mud snails *Nassarius obsoletus*, also known as *Ilyanassa obsoleta*, from many of their habitats and appears to compete with native *Littorina* species for food (Brenchley and Carlton 1983, Yamada and Mansour 1987). Bertness (1984) has shown that grazing and "bulldozing" of sediments by this species prevents accumulation of fine sediments and development of an algal canopy on rocky intertidal sites. When experimentally removed, the snail-free sites gradually became areas of soft sediment. Likewise, removal of snails resulted in increased growth of the salt marsh cord grass *Spartina alterniflora* due to a decrease in herbivory by the snail and an increase in sediment accumulation, which promotes expansion of the root mat.

Veined rapa whelk. *Rapana venosa*, the veined rapa whelk, a native of the Sea of Japan, was first detected in Chesapeake Bay in 1998 (Mann and Harding 2000). Already known as an invasive species in the Black, Adriatic, and Aegean Seas, it is thought to have entered the United States via ballast water. It prefers hard sandy bottoms with salinities of 18-28 ppt and can reach a total length of 150 mm. While juveniles feed on barnacles, mussels, and newly settled and very young oysters, adults feed heavily on soft clams and hard clams. This species has the potential to affect restoration of shellfish habitat in Chesapeake Bay and elsewhere. Distribution of this species is presently limited to portions of Chesapeake Bay, but it will likely spread north to Cape Cod and south to Cape Hatteras (Mann and Harding 2003).

M. membrancea. The European bryozoan *M. membrancea* is believed to have first arrived in U.S. waters sometime in the 1980's (Berman et al. 1990). Now the dominant fouling animal of laminarian kelp in the North Atlantic, it has also been collected on the Pacific coast (Berman et al. 1992, Lambert et al. 1992). Colonies of this animal can become so abundant that the kelp blades are literally weighed down, making the blades more susceptible to damage by wave action (Dixon et al. 1981). Such impacts can directly interfere with attempts to restore kelp habitat.

Potential Threats to Human Health. The lionfish *Pterois volitans,* a native of the Indian Ocean and western Pacific coral reefs, is a favorite aquarium fish because of its colorful appearance. It bears poisonous dorsal, anal, and pelvic spines. The toxin is painful, but is generally not fatal. The lionfish was first noticed in Florida waters in 1994 and may have been introduced when a private aquarium was demolished in the Miami area during Hurricane Andrew in 1992 (Hare and Whitfield 2003). Associated with hard bottoms, coral reefs, and artificial substrates from 26 to 79 m deep, it is generally found on ledges and crevices from Florida to Cape Hatteras, North Carolina. It has also been reported in Puerto Rico. Lionfish feed mostly upon small fish, crabs, and shrimp; however, their impact on local ecosystems has not been assessed.

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REFERENCES

Benson, A. J., and Richerson, M. M. (2004). "Nonindigenous aquatic species of the Northeastern United States," *Aquatic Invaders* 15, 1-9.

Benson, A. J., Jacono, C. C., Fuller, P. L., McKercher, E. R., and Richerson, M. M. (2004). "Summary report of nonindigenous aquatic species in U.S. Fish and Wildlife Service Region 5," prepared for United States Fish and Wildlife Service, Arlington, VA. (*http://cars.er.usgs.gov/Region_5_Report/index.html*).

Berman, J., Harris, L., Lambert, W., Buttrick, M., and Dufresne, M. (1992). "Recent invasions of the Gulf of Maine: Three contrasting strategies," *Conservation Biology* 6, 434-441.

Bertness, M. D. (1984). "Habitat and community modification by an introduced herbivorous snail," *Ecology* 65, 370-381.

Bourdeau, P. E., and O'Connor, N. J. (1999). "Prey preferences of the recently-introduced Western Pacific shore crab, *Hemigrapsus sanguineus*, feeding on molluscs and macroalgae in southeastern Massachusetts." *First National Conference on Marine Bioinvasions. Cambridge, MA. January 24-27, 1999*. Available online at *http://massbay.mit.edu/ exoticspecies/conferences/1999*.

Brenchley, G. A., and Carlton, J. T. (1983). "Competitive displacement of native mud snails by introduced periwinkles in the New England intertidal zone," *Biological Bulletin* 165, 543-558.

Carlton, J. T. (1985). "Transoceanic and intraoceanic dispersal of coastal marine organisms: The biology of ballast water," *Oceanography and Marine Biology: An Annual Review* 23, 313-374.

Carlton, J. T. (2001). *Introduced species in U.S. coastal waters: Environmental impacts and management priorities*. Pew Oceans Commission. Arlington, VA. Available online at *http://www.pewtrusts.org/pdf/env_oceans_species.pdf*.

Carlton, J. T. (2004). "A checklist of the introduced marine and estuarine organisms on the coast of Maine, U.S.A." Available online at *http://www.seagrant.umaine.edu/documents/pdf/invchk.pdf*.

Carlton, J. T., and Hodder, J. (1995). "Biogeography and dispersal of coastal marine organisms: Experimental studies on a replica of a 16th century sailing vessel," *Marine Biology* 121, 721-730.

Carlton, J. T., Reid, D. M., and van Leeuwen, H. (1995). "Shipping Study. The role of shipping in the introduction of nonindigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options," The National Sea Grant College Program/Connecticut Sea Grant Project R/ES-6, Report No. CG-D-11-95.

Cohen, A. N., and Carlton, J. T. (1995). "Biological Study. Nonindigenous aquatic species in a United States estuary: A case study of the biological invasions of the San Francisco Bay and Delta," a report for the United States Fish and Wildlife Service, Washington, DC, and the National Sea Grant Program, Connecticut Sea Grant Publication PB96-166525. Available online at *http://www.anstaskforce.gov/sfinvade.htm*.

Dixon, J., Schroeter, S. C., and Kastendiek, J. (1981). "Effects of the encrusting bryozoan, *Membranipora menbranacea*, on the loss of blades and fronds by the Giant Kelp, *Macrocystis pyrifera* (Laminariales)," *Journal of Phycology* 17, 341-345.

Epifaunio, C. E., Dittel, A. I., Park, S., Schwalm, S., and Fouts, A. (1998). "Early life history of *Hemigrapsus sanguineus*, a non-indigenous crab in the Middle Atlantic Bight (USA)," *Marine Ecology Progress Series* 170, 231-238.

Erlich, P. R. (1989). "Attributes of Invaders and the Invading Processes: Vertebrates." *Biological invasions: A global perspective.* J. A. Drake et al., ed., 1989 SCOPE. John Wiley and Sons, Ltd, 315-328. Available online at *http://www.icsu-scope.org/downloadpubs/scope37/ scope37.html*.

Federal Register. (1999). Executive Order 13112 of February 3, 1999—Invasive Species. Federal Register 64, No. 25. Available at online *http://www.invasivespecies.gov/laws*.

Hare, J. A., and Whitfield, P. E. (2003). *An integrated assessment of the introduction of Lionfish (Pterois volitans/miles complex) to the Western Atlantic Ocean*. National Atmospheric and Oceanographic Administration, National Ocean Service Technical Memorandum CCFHR 1.

Highley, T. L. (1999)."Biodeterioration of wood." *Wood handbook--Wood as an engineering material.* Gen. Tech. Rep. FPL-GTR-113, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI. Available online at *http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr113/ch13.pdf*.

Hoagland, K. E. (1983). *Life history characteristics and physiological tolerances of Teredo bartschi, a shipworm introduced into two temperate zone nuclear power plant effluents*. Hemisphere Publishing Co., Miami Beach, FL, 609-622.

Jensen, G. C., McDonald, P. S., and Armstrong, D. A. (2002). "East meets west: Competitive interactions between green crab *Carcinus maenas*, and native and introduced shore crab *Hemigrapsus* sp," *Marine Ecology Progress Series* 225, 251-262.

Lambert, W. J., Levin, P. S., and Berman, J. (1992). "Changes in the structure of a New England kelp bed: The effects of an introduced species," *Marine Ecology Progress Series* 88, 303-30.

Lavoie, D. M., Smith, L. D., and Ruiz, G. M. (1999). "The potential for intracoastal transfer of nonindigenous species in the ballast water of ships," *Estuarine, Coastal and Shelf Science* 48, 551-654.

Lohrer, A. M., and Whitlach, R. B. (1997). "Ecological studies on the recently introduced Japanese Shore Crab (*Hemigrapsus sanguineus*), in Eastern Long Island Sound." *Proceedings of the 2nd Northeast Conference on Nonindigenous Aquatic Nuisance Species*. Connecticut Sea Grant Publication CTSG-97-02, 49-60.

Mann, R., and Harding, J. M. (2000). "Invasion of the North American Atlantic Coast by a large predatory Asian mollusk," *Biological Invasions* 2, 7-22.

Mann, R., and Harding, J. M. (2003). "Salinity tolerance of larval *Rapana venosa*: implications for dispersal and establishment of an invading predatory gastropod on the North American Atlantic coast," *Biological Bulletin* 204, 96-103.

Massachusetts Aquatic Invasive Species Working Group. (2002). *Massachusetts Aquatic Invasive Species Management Plan*. State of Massachusetts. Available online at *http://www.anstaskforce.gov/Mass_AIS_Plan.pdf*).

Massachusetts Institute of Technology. (2004). "Introduced and cryptogenic species of the North Atlantic, Sea Grant Center for Coastal Resources." Available online at *http://massbay.mit.edu/exoticspecies/exoticmaps/index.html*.

McDermott, J. J. (1991). "A breeding population of the Western Pacific crab *Hemigrapsus sanguineus* (Crustacea: Decapoda: grapsidae) established on the Atlantic coast of North America," *Biological Bulletin* 181, 195-198.

National Marine Fisheries Northeast Science Center. (2004). "News. Invasive sea squirt alive and well on Georges Bank." News Release November 19, 2004. Available online at *http://www.nefsc.noaa.gov/press_release/2004/news04.19.htm*.

New York Sea Grant. (2001). *Aquatic nuisance, non-indigenous and invasive species.* New York Sea Grant, Stony Brook, NY. Available online at *http://www.seagrant.sunysb.edu/NYSG@30/aquaticinv.htm*.

Padilla, D. K., and Williams, S. L. (2004). "Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems," *Frontiers in Ecology and the Environment* 3, 131-138.

Percival, S. R., and Wilson, K. (2001). "Feeding and substrate preferences of the Japanese shore crab, *Hemigrapsus sanguineus*." *Second International Conference on Marine Bioinvasions*. New Orleans, LA. April 9-11, 2001. Available online at *http://massbay.mit.edu/exoticspecies/conferences/2001/*.

Ray, G. L. (2005) "Invasive animal species in marine and estuarine environments: Biology and ecology." Aquatic Nuisance Species Research Program, Technical Report ERDC/EL TR-05-2, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Ruiz, G. M., Fofonoff, P., Carlton, J. T., Wonham, M. J., and Hines, A. H. (2000). "Invasion of coastal marine communities in North America: Apparent patterns, processes, and biases," *Annual Review in Ecology and Systematics* 2000, 481-531.

State of Vermont. (2004). "Non-native plant and animal species in aquatic and wetland habitats in Vermont." Available online at *http://www.anr.state.vt.us/dec/waterq/lakes/docs/ans/lp_ans-list.pdf*.

Torchin, M. E., Lafferty, K. D., Dobson, A. P., McKensie, V. J., and Kuris, A. M. (2003). "Introduced species and their missing parasites," *Nature* 421, 628-630.

Weigle, S. M., Smith, L. D., Carlton, J. T., and Pederson, J. (2005). "Assessing the risk of introducing exotic species via the live marine species trade," *Conservation Biology* 19, 213-223.

Williams, J. D., and Meffe, G. K. (1999). "Nonindigenous species." *Status and Trends of the Nation's Biological Resources.* United States Geological Survey. Available online at *http://biology.usgs.gov/s+t/SNT/index.htm.*

Wolfe, L. M. (2002). "Why alien invaders succeed: Support for the escape-from-enemy hypothesis," *American Naturalist* 160, 705-711.

Yamada, S. B., and Mansour, R. A. (1987). "Growth inhibition of native *Littorina saxatilis* (Olivi) by introduced *L. littorea*," *Journal of Experimental Marine Biology and Ecology* 105, 187-196.

APPENDIX A: NIS LISTINGS BY STATE FOR THE NORTH ATLANTIC REGION

Species	Group	ME	MA	NH	VE	RI	CN	NY	NJ	PA	DE	MD	VA
Perkinsis marinus	Protozoa		MA						NJ			MD	VA
Haplosporisium nelsoni	Protozoa		MA						NJ			MD	VA
Bonamia ostrea	Virus	ME	MA										
Cliona vastifica	Porifera		MA										
Halichondria bowerbankia	Porifera	ME	MA			RI	CN	NY					
Blackfordia virginica	Hydromedusa											MD	VA
Moerisia lysonsi	Hydromedusa											MD	
Maeotias inexspectata	Hydromedusa												VA
Maeotias marginata	Hydromedusa												VA
Nematostella vectensis	Anemone											MD	VA
Diadumene lineata	Anemone	ME	MA										VA
Sagartia elegans	Anemone		MA										
Cordylophora caspia	Hydrozoa	ME											
Convoluta convoluta	Platyhelminth	ME											
Tubificoides heterochaetus	Oligochaete												VA
Demonax flecatus	Polychaete												VA
Demonax sp.	Polychaete												VA
Namanereis littoralis	Polychaete												VA
Boccardiella ligerica	Polychaete											MD	VA
Boccardiella probsoscidea	Polychaete	ME											
Ficopomatomus enigmaticus	Polychaete											MD	VA
Janua pagenstecheri	Polychaete	ME				RI							
Bankia gouldii	Bivalve											MD	
Crassostrea ariakensis	Bivalve												VA
Crassostrea gigas	Bivalve		MA									MD	VA
Cyrenoida floridana	Bivalve											MD	VA
Ischadium recurvum	Bivalve											MD	VA
Ostrea edulis	Bivalve	ME	MA			RI							
Mytilopsis leucopaeata	Bivalve		MA					NY					
Rangia cuneata	Bivalve		MA					NY				MD	VA
Teredo bartschi	Bivalve		MA				CN		NJ				VA
Teredo furcifera	Bivalve		MA						NJ				VA
Teredo navalis	Bivalve	ME	MA					NY					VA
Venerupis philippinarum	Bivalve		MA										
Assiminea succinea	Gastropod											MD	VA
Eupleura sulcidentata	Gastropod												VA
Littorina littorea	Gastropod	ME	MA			RI			NJ		DE		VA
Melampus floridanus	Gastropod											MD	VA
Mysotella myosotis	Gastropod		MA										

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Species	Group	ME	MA	NH	VE	RI	CN	NY	NJ	PA	DE	MD	VA
Pyostella myosotis	Gastropod												VA
Rapana vensoa	Gastropod												VA
Stramonita haemastoma	Gastropod											MD	VA
Vitrinella floridana	Gastropod												VA
Tritonia plebeia	Nudibranch	ME	MA										
Placida dendritica	Nudibranch		MA										VA
Tenellia adspersa	Nudibranch		MA										VA
Argulus japonicus	Copepod											MD	VA
Eurytemora affinis	Copepod		MA					NY					VA
Mytilcola sp.	Copepod											MD	
Balanus amphitrite	Barnacle		MA					NY	NJ			MD	VA
Balanus subalbidus	Barnacle		MA										
Chthamalus fragilis	Barnacle					RI							
Elminus modestus	Barnacle		MA										
Loxothylacus panopaei	Barnacle											MD	VA
Amphilochus sp.	Amphipod												VA
Apocorophium acutum	Amphipod												VA
Monocorophium acheruscium	Amphipod												VA
Monocorophium insidiosum	Amphipod												VA
Corophium volutator	Amphipod	ME	MA										
Caprella mutica	Amphipod	ME											
Cheurla terebrans	Amphipod		MA										
Gitanopsis sp.	Amphipod											MD	VA
Microdeutops gryllotalpa	Amphipod		MA	RI			CN						
Stenothoe gallensis	Amphipod												VA
Ligia exotica	Isopod								NJ			MD	VA
Ligia oceanica	Isopod	ME											
Ianiropsis sp.	Isopod	ME											
Limnoria sp.	Isopod		MA										
Sphaeroma terebrans	Isopod												VA
Synidotea laevaidorsalis	Isopod								NJ				
Americamysis almyra	Mysid											MD	VA
Praunus flexuosus	Mysid	ME	MA										
Carcinus maenas	Crab	ME	MA	NH		RI	CN	NY	NJ		DE	MD	VA
Hemigrapsus sanguineus	Crab	ME	MA	NH		RI	CN	NY	NJ		DE	MD	VA
Anisolabis maritima	Insect	ME	MA										VA
Brachydeutera longipes	Insect											MD	
Placopsidella erandis	Insect											MD	
Placopsidella grandis	Insect												VA
Procanace diannae	Insect												
Aetea anguina	Bryozoan		MA										
Membranipora membranacea	Bryozoan	ME	MA			RI	CN						
Stephanella hina	Bryozoan		MA										
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Species	Group	ME	MA	NH	VE	RI	CN	NY	NJ	PA	DE	MD	VA
Alyconidium sp.	Bryozoan	ME											
Bugula neritina	Bryozoan	ME	MA										VA
Bulbella abscondita	Bryozoan		MA										
Tangenella muelleri	Bryozoan		MA										
Tangenella appendiculata	Bryozoan		MA										
Barentsia benedini	Kamptozoan		MA										VA
Barentsia carteri	Kamptozoan											MD	
Loxosomatoides laevis	Kamptozoan											MD	VA
Ascidiella aspersa	Tunicate		MA			RI	CN						VA
Botrylloides diegensis	Tunicate	ME	MA	NH		RI	CN						
Botrylloides violacteus	Tunicate	ME	MA										VA
Botryllus schosseri	Tunicate	ME	MA										VA
Didemnum cf. lahillei	Tunicate	ME	MA	NH		RI							
Diplosoma macdonaldi	Tunicate	ME	MA			RI	CN						
Diplosoma listerianum	Tunicate		MA										VA
Ecteinascidia turniata	Tunicate												VA
Mogula manhatetensis	Tunicate	ME	MA								NJ*	MD	VA
Styela clavata	Tunicate	ME	MA	NH		RI	CN	NY					VA
Styela canopus	Tunicate		MA										VA
Styela plicata	Tunicate		MA										VA
Alosa aestivalis	Fish				VE			NY		PA			VA
Alosa pseudoharengus	Fish		MA	NH	VE			NY		PA		MD	VA
Alosa sapidissima	Fish		MA		VE			NY		PA		MD	VA
Anguilla rostrata	Fish									PA			
Dorosoma cepedianum	Fish				VE			NY		PA			VA
Dorosoma petenense	Fish									PA	DE	MD	VA
Fundulus heteroclitus	Fish			NH						PA			
Gadus morhua	Fish											MD	VA
Gobionellus hastatus	Fish		MA										
Hypsoblennius ionthas	Fish		MA										
Morone saxatilis	Fish								NJ	PA		MD	VA
Oncorhynchus gorbuscha	Fish							NY		PA		MD	
Oncorhynchus keta	Fish	ME											
Oncorhynchus kisutch	Fish	ME	MA				CN	NY		PA	DE	MD	VA
Oncorhynchus nerka nerka	Fish		MA		VE		CN	NY		PA			
Oncorhynchus tshawytscha	Fish	ME	MA	NH	VE		CN	NY	NJ	PA	DE	MD	VA
Petromyzon marinus	Fish							NY		PA			
Pterois volitans	Fish							NY	NJ				
Salmo salar	Fish	ME	MA		VE		CN	NY	NJ	PA	DE	MD	VA

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