Risk Assessment Review of Invasive Species in Long Island Sound

by
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Background

The Long Island Sound Study (LISS) completed a Comprehensive Conservation and Management Plan in 1994 in order to fully restore the health of Long Island Sound (LIS). The Plan identified seven topics to be addressed, one of which is 'living resources and habitat management'. The increase and impacts of invasive species in LIS comprise an emerging issue under the topic of living resources and habitat management. In order to address this issue, a working group involving members of the Science and Technical Advisory Committee (STAC) and LISS members wrote a management plan for aquatic nuisance species (ANS) in Connecticut (Connecticut Aquatic Nuisance Species Management Plan 2006). As a result of these efforts, which have been led by Connecticut Sea Grant and the Connecticut Department of Environmental Protection, a list of priority nuisance species and their vectors has been constructed. In an attempt to evaluate the risk associated with the introduction of these priority species, the Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process (Aquatic Nuisance Species Task Force 1996) was used as guidelines to formally assess the status of non-native species in Connecticut's marine environment. This report has been prepared to support development of a Long Island Sound Aquatic Nuisance Species Management Plan. The information provided may be revised and supplemented for the final ANS plan.

Following the format of the review process, the risk associated with the introduction of a particular species was estimated as a function of the probability of establishment, consequence of establishment, as well as organism and pathway risk potential (Aquatic Nuisance Species Task Force 1996). Pertinent management questions and recommendations were then posed based on the outcome of the risk analyses. A more refined priority list of species identified through this process will hopefully serve as a component of an anticipated LIS ANS Management Plan.

Introduction

The introduction of invasive species is a critical environmental issue in the marine environment, having been identified as one of the major threats to the maintenance of biodiversity and ecosystem functioning (Carlton and Geller 1993, Carlton 1996, Ruiz et al. 1999, Crooks and Khim 1999, Mack et al. 2000, Branch and Steffani 2004). Invasive species act as vectors for new diseases, degrade habitat structure, and threaten fisheries (Vitousek et al. 1996, Carlton 1999, Mack et al. 2000). In their new environment, invasive species are often free of predators, competitors, parasites, and diseases that might otherwise regulate their populations in native regions (Lohrer 2000, Mack et al. 2000). As a result of being freed from natural control agents, these invaders can direct more energy toward growth and reproduction. This enables invasive species to reduce or eliminate populations of native species through ecological processes such as predation and competition. The reduction or elimination of native populations may not only have negative impacts on ecosystem function and patterns of species diversity and abundance, but on the economy and public health of the affected region as well (Lafferty and Kuris 1996, Vitousek et al. 1997).

The number of invasions in a given region is often underestimated, and the ecological effects of the invaders can be greater than predicted (Bax et al. 2001). More recently, scientists have begun to explicitly demonstrate the magnitude of the problem (Carlton 1999, Ruiz et al. 1999). Both university and agency researchers have been researching methods to control invaders, but plans for control of marine species are only in their early years and have demonstrated mixed success (Bax et al. 2001). Among researchers, the general consensus is that a successful invasive species policy should (1) prevent new introductions and (2) control established populations in an environmentally sound and safe manner (Bax et al. 2001). In developing such a policy, it is important to establish the nature and magnitude of the problem, then determine the ecological risks associated with a specific introduction.

Ecological risk assessments are used to describe an array of methodologies and techniques concerned with estimating the likelihood and consequences of undesired events that occur in the environment. While traditionally applied to investigating the effects of chemical pollutants, they are currently being used to evaluate such biological stressors as the introduction or transfer of marine organisms (Hayes 1997). Risk assessments can be either qualitative or quantitative, and there are benefits and disadvantages to both methods. For example, the Weed

Risk Assessment of Australia (Groves et al. 2001) and the Ecological Risk Assessment Framework of the U.S. Government (2002) are ecological risk assessments based upon expert opinion and qualitative analysis. Qualitative assessments outline the constituent components of the introduction process and are a good basis upon which to address risk. However, they generally do not provide an index to gauge uncertainty or the relative value of alternative risk reduction (Aquatic Nuisance Species Task Force 1996). In addition, a judgment made by an assessor is not always impartial, and could result in biased conclusions. Quantitative analyses like the Environmental Risk Management of Introduced Aquatic Organisms in Aquaculture (Kohler 1992) and Ecological Predictions and Risk Assessment (Kolar and Lodge 2002) are repeatable and objective, and often provide insight to economic damage caused by the biological stressor. However, one caveat to this type of approach is that the information required to complete the assessment isn't always available, leaving holes in the analysis and preventing a terminal outcome. In fact, because detection rates of new invasions differ among habitat and regions, and because invasive species may behave differently in their recipient habitats, it is often years before such information is available to the public and /or science communities.

The Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process (Orr, 1995) was designed to deal with the caveats presented above, as well as to meet the requirements of the Aquatic Nuisance Prevention and Control Act (1990; Hayes 1997). It was modified from the Generic Non-Indigenous Pest Risk Assessment Process (Orr et al. 1993; USDA's Animal and Plant Health Inspection Service (APHIS)) that evaluates the introduction of nonindigenous plant pests. The APHIS process has been systematically validated with numerous organism assessments and high risk pathway studies, thus it serves as a valuable component in the design of the Review Process. The approach and philosophy of the Review Process have also been heavily influenced by the National Research Council's "Ecological Paradigm" (1993), the Environmental Protection Agency's "Ecological Framework" (1992), the United States Congress Office of Technology Assessment's nonindigenous species report (1993), and the Forest Service's pest risk assessments on nonindigenous timber pests (1991).

The Aquatic Nuisance Species Task Force also incorporated the following criteria into their Review Process, as modified from Fischoff et al. (1981): (1) comprehensive, (2) logically sound, (3) practical, (4) conducive to learning, and (5) open to evaluation. In order to fulfill the above criteria, the risk assessment was designed so that assessors could review the subject in detail, identify sources of uncertainty, and accommodate new information as it becomes available. This ensures that the risk assessments are up-to-date, reliable, unbiased, and adequate based on the availability of resources. In order to be conducive to learning, the risk assessments were designed to have a broad scope so as to serve as a template for similar and/or future assessments; but the design also requires a level of detail so that each can be reviewed by the qualified individuals.

The main objective of the Review Process is to provide a standardized method for evaluating the risk of invasive species in recipient environments and if necessary, to determine the correct risk management steps needed to mitigate that risk. This approach is flexible in that it incorporates a variety of ways to assess the risk associated with the invasive organism based on availability or lack of resources and the accessibility of biological information.

The Review Process' specific function is to develop a risk assessment and risk management process. The risk assessment process can be used to evaluate recently established or impending invasive organisms, individual pathways, and the risk associated with individual pathways. The risk management process is designed to protect available resources by reducing the probability of and risk associated with unintentional introductions (ANS Task Force 1996). The Review Process may be used in a purely subjective manner, but it may also be quantified to the extent possible/necessary depending upon the needs of the analysis. Overall, the approach is systematic, consistent, and often correctly identifies key components of invasion risk (e.g. initial introduction, propagule survival, establishment, spread, and manifestation of ecological effects; Orr 1995, Hayes 1997). However, this approach cannot determine the acceptable risk level or whether, when, and how a particular organism will become established. These are ecological events that are not easily predicted even with comprehensive data sets. For the purpose of the Review Process, such predictions are presented as value judgments made by the assessor. Often times, the most qualified and conscientious person available conducts the assessments, but to some extent, the quality of the analysis will always reflect the capability of the individual assessor (ANS Task Force 1996). This Review Process counters this limitation with a required judgment from each assessor addressing the certainty of their statements in an effort to reduce bias when dealing with a particular organism.

This semi-qualitative, and unbiased approach, was used to assess the risk associated with 10 of the priority species identified by the CT Aquatic Nuisance Species Management Plan. In doing so, the Review Process provided a framework where scientific, technical, and other relevant information was organized into a format that is both useful and understandable to managers and decision makers. The components and steps of this process are outlined below.

Overview of the Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process

In order to evaluate the risks associated with the introduction of an aquatic organism, it is necessary to assess the probability that a species will become established and the consequences of that establishment. The Review Process addresses the major environmental components in two major steps, further divided into seven basic elements. The cumulative information under these elements provides the data to assess the risk under said elements. Each of the elements is rated as high, medium, or low (e.g. High = unacceptable risk or an organism of major concern; medium = unacceptable risk or an organism of moderate concern; low= acceptable risk or an organism of little concern) to dictate whether or not mitigation is justified. By these standards, mitigation is only justified for elements that receive high or medium ratings. It is proposed that those organisms receiving high or medium ratings undergo a second risk analysis to determine correct mitigation steps. For each element, there is also an uncertainty rating ranging from very certain to very uncertain. This rating reflects how certain the assessor is with regards to the information for a given element and the resultant risk rating.

The first step requires the assessment of the probability of organism establishment. This is particularly important for an organism whose pathway is unknown, or an organism which has been recently introduced. There are four elements under this step. The first is to estimate the probability of the organism being on, with, or in the pathway, based upon whether the organism shows a considerable spatial and temporal association with the pathway. Here, the pathway is defined as the vector or means by which the organism is introduced to a specific area. If the pathway is unknown, all possible vectors associated with the transport of ecologically similar organisms are evaluated. The second element is to estimate the probability of the organism surviving in transit. Factors that would influence the survival of an organism in transit is a reflection of its hitchhiking ability, life cycle stage during transit, number of individuals expected to be associated with the pathway, and whether or not it was deliberately introduced. The third element addresses the probability of the organism colonizing and maintaining a stable population. Stability would depend on whether or not the organism came into contact with an adequate food resource and suitable habitat, encounters significant abiotic and biotic environmental resistance, and was able to reproduce. One interesting example is the zebra mussel *Dreissena polymorpha* which was likely introduced multiple times into the Great Lakes, but did not become established until the mid- to late- 1980s (Munawar et al. 2005). This third element of the review process identifies the importance of timing in colonization by an invasive species. The final element is intended to estimate the probability of dispersal and the establishment of connectivity among populations.

The second step requires the assessment of the consequence of organism establishment and three elements fall under this step. The first element calls the analyst to estimate the economic impact if the organism becomes established for which the assessor should consider the economic importance of hosts, damage to natural resources, effects on subsidiary industries, exports, and control costs. The second element calls for the estimation of environmental impact if the organism becomes established. Here the assessor might examine ecosystem destabilization, reduction in biodiversity, reduction or elimination of keystone species, reduction or elimination of endangered or threatened species, and effects of control measures. If applicable, impacts on the human environment, such as parasites or pathogens, should be included under this element. In examining ecosystem destabilization and reduction in biodiversity, it is suggested that the assessor pay special attention to distribution and abundance of native species resulting from alterations in relationships such as predation, prey availability, and habitat availability. Food web studies provide significant insight to such relationships. The third element requires the estimation of impact from social and/or political influences, i.e. a perceived impact that might include aesthetic damage, consumer concerns, and political repercussions. It is also important to note that positive impacts resulting from an invasion should be recorded in this section, i.e. biocontrol agent, sport fish, aquaculture, etc.

The final rating for probability of establishment is assigned the value of the element under that step with the lowest rating. Likewise, the final rating for the level of certainty is assigned the lowest level of certainty among all elements under step one. In contrast, the final rating for the consequence of establishment is assigned the value of the element with the highest rating between economic and ecological impacts. The overall risk for the organism is assigned a single value based on both the probability of establishment and consequence of establishment. The assessor then uses this final estimate as a direction for the correct mitigation. In addition, the assessor details the life cycle, distribution, and natural history of the organism concerned and the pathway being considered.

Risk Analyses of Potential Invaders of Long Island Sound, CT

The risk analysis review process was carried out on two recently established invaders of Long Island Sound, CT (*Hemigrapsus sanguineus* and *Didemnum* sp.), and ten potential invaders of the same waters: *Eriocher sinensis*, *Undaria pinnatifida*, *Grateloupia turuturu*, *Sargassum muticum*, *Rapana venosa*, *Pterois volitans*, *Styela plicata*, *Hemigrapsus penicillatus*, *Caulerpa taxifolia*, and *Crassostrea ariakensis*. These potential invaders were chosen based on their introduction into areas in close proximity to Long Island Sound or similar environments. The process described above was conducted for each species. Information to support each element under each step, as well as the details on the life cycle, distribution, and natural history of the organism, were taken from primary scientific literature, online databases, and personal communication with those individuals studying the organism of question.

The following risk analyses are presented here in the format designed by Orr (1995).

Hemigrapsus sanguineus and *Didemnum* sp. A are both nonindigenous species that recently invaded and are currently established in Long Island Sound. The risk analysis review for these species was conducted in an effort to validate the process, but also because little is known about these invaders despite the fact that they have maintained breeding populations in the Sound for a number of years.

1. Risk Assessment for the Asian shore crab *Hemigrapsus sanguineus*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM	*Hemigrapsus sanguineus*	**FILE NO.**	1
ANALYST	Kari Heinonen	**DATE**	09/28/2005
PATHWAY	Unknown	**ORIGIN**	Western Pacific Ocean

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

Life Cycle/Life History: *Hemigrapsus sanguineus* is a grapsid crab that compensates for low reproductive output by producing multiple broods over several years and survives to large sizes. Fully grown females can likely produce >50,000 eggs per brood, which is many more than the largest females from other species. (McDermott 1998a) The eggs are of intermediate size (compared to other co-ocurring crabs). Eggs hatch into larvae and then proceed to molt through 5 zoeal stages to become megalopae. Megalopea can be found in the water column and the benthos. The time it takes to hatch from the first instar stage is ≥ 25 days under optimal conditions. (Hwang et al. 1993, Epifanio et al. 1998, Lohrer 2000). Females first begin to produce eggs in the spring, and settlement usually occurs in late summer and fall. Settled crabs grow rapidly at first, molting 4-5 times in their first month, and growth slows with decrease in temperature and after maturity. Recruitment is highest in rocky intertidal habitats (Lohrer and Whitlatch 1997, Lohrer 2000).

Distribution: The crab was first discovered on the New Jersey coast in 1988, and has since expanded its geographic range both north and south. It is now found from Maine to North Carolina (expected to reach Florida) (Hemi-List Serve).

Natural History: *Hemigrapsus sanguineus* is a common and widespread crab along rocky coastlines in the Western Pacific Ocean, i.e. from Hong Kong, China (22ºN) to Russia (49ºN). It appeared on the New Jersey coast in 1988. (reviewed by McDermott 1998b) A rhizocephalan parasitic barnacle (*Sacculina polygenea*) attacks the species in Asia, but is completely absent from eastern North America (Lohrer 2001). Older life stages are associated with a single specific habitat type: rocky intertidal areas strewn with cobbles and boulders (Lohrer et al. 2000) as well as subtidal areas of similar grain size (personal observations). The crab is completetly omnivorous, and co-occurs with other many other crustaceans in its native range.

II. PATHWAY INFORMATION (include references):

The introduction of *Hemigrapsus sanguineus* was apparently accidental (Lohrer 2001), and possibly associated with ocean-going vessel traffic. Planktonic life stages may have arrived in ballast water in 1985, or adult stages could have been transported in 1988. Juvenile/adult *H. sanguineus* could have been transported in a matrix of organisms on a fouled vessel hull. (Gollasch 1999, Lohrer 2001) Ships from a variety of Asian ports arrive in the eastern U.S. every year. The vector of transport, lifestage during transport, and exact source location are presently unknown.

III. RATING ELEMENTS: Rate statements as low, medium, or high.

Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = RC

It is likely that *H. sanguineus* was introduced into the Western Atlantic via discharge of ballast water by ocean-going vessels (Williams and McDermott 1990). Larval dispersal from native range is not likely, due to current direction and distance between the Western Pacific and Western Atlantic (Gollasch 1999).

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = RC

It is probable that the organism would survive in transit. *Hemigrapsus sanguineus* tolerates a wide range of temperatures and salinities (i.e. below freezing to ≥30ºC Lohrer et al. 2000; 29.5‰ to 42‰), and would probably survive transport in ballast water. Adults might also survive if transported in fouling assemblages on hulls of ocean-going vessels. Its congener *Hemigrapsus pencillatus* has been observed nestled in fouling communities attached to the hulls of vessels traveling long distances (Gollasch 1999).

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Hemigrapsus sanguienus has successfully colonized and maintained a population where it was first discovered in New Jersey in 1988. Sampling in New Jersey from 1988 to 1995, revealed not only a sustained population, but also an increase in the number of individuals per square meter (McDermott 1998b).

Successful colonization by a particular species is somewhat contingent upon similarities between native and invaded habitats, as well as availability of resources in the recipient region (G). Many of the same physical and climatological conditions that occur along Japan's eastern coastline also occur along the United States eastern coastline (McDermott 1998b). Within a given area, *H. sanguienus* can tolerate a wide range of physical conditions (Lohrer et al. 2000). Populations of *H. sanguineus* in its native range are parasitized by a rhizocephalan barnacle; whereas the barnacle is absent from its invaded range. Also, *H. sanguineus* comes from a region of relatively high crab diversity compared to the eastern coastline of the US, and interference from other crabs may be less important in invaded regions, such as Long Island Sound.

H. sanguineus in its native habitat is found on predominantly exposed rocky shorelines, which are also very common features of the eastern coast of North America (Lohrer et al. 2000). The invaded habitats also contain food items common to the native habitats: turf-forming red algae, green sheet-like algae, mytilid bivalves, small herbivorous snails, small crustaceans, and polychaete worms (Lohrer et al. 2000). The similarity in physical conditions, habitat type, and food resources between native and invaded regions most likely contributed to the successful invasion of Connecticut by *H. sanguineus*.

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

In the western Pacific, *H. sanguineus* ranges from approximately 20º to 50ºN latitude (McDermott 1998b). Given the similarities between the native and invaded regions, it is likely that the crab could reach a latitudinally equivalent distribution in the western Atlantic (i.e. Gulf of St. Lawrence to Cuba; McDermott 1998b, Lohrer et al. 2000). *Hemigrapsus sanguineus* already ranges from southern Maine to North Carolina, having extended its geographic range from New Jersey in 1988 (list serve). In addition, *H. sanguineus* was once thought to be a strictly upper-intertidal crab as it is found in its native habitat. However, surveys and observations show that the crab has become established throughout the intertidal and is also found in subtidal habitats in Long Island Sound (Lohrer et al. 2000).

<u>CONSEQUENCE OF ESTABLISHMENT</u>

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

The diet of *H. sanguineus* regularly consists of juvenile bivalves, including mussels, clams, and oysters (all economically important species (Brousseau et al. 2000, Lohrer et al. 2000). In addition to commercial and recreational harvest of these species, mussel beds and oyster reefs serve as a nursery ground for other commercially important fish and crustacean species (snappers, grouper, cunner, tautog, etc.). Therefore, declines in bivalve populations due to increased consumption by *H. sanguineus* may have cascading effects on other marine life that depend on the bivalves as a resource, i.e. commercially important fish species, other crustaceans.

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Hemigrapsus sanguineus may limit recruitment of several functionally important invertebrate species in the region, e.g. replacing other resident crab species like the green crab *Carcinus maenas* and the mud crab *Panopeus herbstii* (Lohrer and Whitlatch 2002). Such replacement could result in trophic cascades whereby there is a net negative influence on mussel and snail populations, important grazers in the intertidal zone. While green crabs actually consume more animal matter on a per capita basis, densities of *H. sanguineus* are often 60 to 80 times greater and the collective effects of *H. sanguineus* are thought to be more important.

However, the impacts of *H. sanguineus* are not limited to the intertidal zone as subtidal observations of the invader have been made in Connecticut (i.e. oyster reefs and mussel beds as described above). The replacement of prey species important to near-shore fishes or decline of prey items of near-shore fishes may occur as a result of the *H. sanguineus* introduction. This could result in a net negative influence on fish populations that are already declining, e.g. tautog. (Heinonen, current research).

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = L
Uncertainty Code (VC-VU) = RU

Because very few ecological and economic impacts resulting from the *H. sanguineus* introduction have been quantified, it is difficult to say whether there will be impacts on social and political aspects of Connecticut. In a purely hypothetical example, declines in economically important shellfish or fish populations caused by the *H. sanguineus* introduction, could result in a future decline of the number of shellfish harvested. Hence, one might predict a negative impact on local economies. In contrast, there is anecdotal evidence that *Hemigrapsus* is consumed by humans in its native range. Also, *Hemigrapsus* makes a great candidate for bait, as many economically important fish species are known to consume the crab (i.e. tautog, cunner, sea bass, etc.) If use of the crab for human consumption and/or bait increased, there may be the possibility of a positive effect on the local economy, as long as bait shops and seafood shops targeted the correct market. Personal communication with workers from the CT DEP reveal that bait shops in East Haven and Niantic are now selling the crab as fish bait.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

This analysis identifies *Hemigrapsus sanguineus* as an organism of major concern. Mitigation is justified.

V. SPECIFIC MANAGEMENT QUESTIONS:

- Many studies have focused on prey items of the *H. sanguineus*, but not many have focused on predators of the crab. Are there larger animals native to CT that consume the crab? What type of impact will this have on the CT coastline and near-shore waters?

- Are monitoring projects set up to track long term impacts?

- How are the crabs transported to the U.S.? Is there a way to prevent this (i.e. ballast water monitoring?) to slow the expansion of the crab into uninvaded areas, as well as to prevent the export of the crab to areas where it is not yet established?

- If adults are transported, and these adults are infected with the parasitic barnacle, will the barnacle successfully invade as well- now that there is already a host population established?

VI. RECOMMENDATIONS:

- Continue monitoring various habitats and sites within CT to document the spread of the crab into "unusual" or uninvaded habitats and/or sites.

- Continue research investigating the impacts on the invaded ecosystem, including CT native fauna and flora so that appropriate management can be implemented for these species.

- Monitor vessel traffic and ballast water for future introductions.

VII. MAJOR REFERENCES:

Brousseau DJ, Korchari PG, Pflug C. 2000. Food preference studies of the Asiatic shore crab (*Hemigrapsus sanguineus)* from Western Long Island Sound. In Pederson J (ed). *Marine Bioinvasions: Proceeding of the 1st National conference*, Cambridge, MA, pp. 200-207.

Epifanio CE, Dittel AI, Park S, Schwalm S, Fouts A. 1998. Early life history of *Hemigrapsus sanguineus* in the Middle Atlantic Bight. *Marine Ecology Progress Series.* 170: 231-238.

Gollasch S. 1999. The Asian decapod *Hemigrapsus pencillatus (*de Haan) (Grapsidae, Decapoda) introduced in European waters: status quo and future perspective. *Helgoländer Meeresuntersuchungen.* 52: 359-366.

Hwang SG, Lee C, Kim CH. 1993. Complete larval development of *Hemigrapsus sanguineus* (Decapoda, Brachyura, Grapsidae) reared in laboratory. *Korean Journal of Systematic Zoology.* 9(2): 69-86.

Lohrer AM. 2000. Mechanisms and consequences of an exotic crab species invasion. Doctoral Dissertation, Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, CT, USA. 147 pp.

Lohrer AM. 2001. The invasion by *Hemigrapsus sanguineus* in eastern North America: A review. *Aquatic Invaders: The Digest of National Aquatic Nuisance Species Clearinghouse.* 12(3): 1-14.

Lohrer AM, Fukui Y, Wada K, Whitlatch RB. 2000. Home and away: comparisons of resource utilization by a marine species in native and invaded habitats. *Biological Invasions.* 2(1): 41-57.

Lohrer AM and Whitlatch RB. 1997. Ecological studies on the recently introduced Japanese shore crab (*Hemigrapsus sanguineus)*, in eastern Long Island Sound. In Balcolm (ed.)

Proceedings of the Second Northeast Conference on Nonindigenous Aquatic Nuisance Species, Burlington, VT, 18-19 April 1997. Connecticut Sea Grant College Program, Groton, CT, USA, pp. 49-60.

Lohrer AM and Whitlatch RB. 2002. Interactions among aliens: apparent replacement of one exotic species by another. *Ecology*.
McDermott JJ. 1998a. The western Pacific brachyuran *Hemigrapsus sanguineus* (Grapsidae) in its new habitat along the Atlantic coast of the United States: reproduction. *Journal of Crustacean Biology*. 55(2): 289-298.

McDermott JJ. 1998b. The western Pacific brachyuran *Hemigrapsus sanguineus* (Grapsidae) in its new habitat along the Atlantic coast of the United States: geographic distribution and ecology. *ICES Journal of Marine Science*. 55(2): 289-298.

Williams AB and McDermott JJ. 1990. An eastern United States record for the Western Indo-Pacific crab, *Hemigrapsus sanguineus (*Crustacea, Decapoda, Grapsidae). *Proceedings of the Biological Society of Washington.* 103(1): 108-109.

2. Risk Assessment for the fouling tunicate *Didemnum* sp. A

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM	*Didemnum* sp. A	**FILE NO.**	2
ANALYST	Kari Heinonen	**DATE**	10/05/2005
PATHWAY	Human mediated	**ORIGIN**	Europe or New Zealand?

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

Life Cycle/Life History: Like all colonial ascidians, *Didemnum* sp. A reproduces sexually and broods its larvae. Newly settled juveniles have been found from July to November, with peak settlement occurring from late August to early September. In addition to forming new colonies through larval settlement, *Didemnum* sp. A can form new colonies asexually through fragmentation. Lobes may break off from rope-like colonies, reattach to substrata, and thrive in their new location. These pieces that break off, may also be brooding larvae at the time, increasing the distance of larval dispersal (Bullard et al. submitted)

Distribution: Since its introduction in the 1980s-1990s, *Didemnum* sp. A has become successfully established on the east and west coasts of North America. It ranges approximately 750km of coastline on the east coast (Eastport, ME to Shinnecock, NY), and approximately 800km on the west coast (Humboldt Bay to Port San Luis, CA). Large populations have also recently been found in Puget Sound, WA and southwest British Columbia. (Bullard et al. submitted) *Didemnum* sp. A also occurs at deeper subtidal sites off New England, e.g. Georges Bank. (USDA 2003)

Natural History: Colonies exhibit a wide range of morphological variation, with color morphs ranging from pink to tan to pale orange and shapes that range from rope-like to undulating mats. Colonies grow on a wide variety of hard substrata, but are very common on docks, pilings, subtidal rock outcrops, and gravel. It appears that growth form may be related to habitat type, current velocity, or space availability: rope-like forms are common on vertical substrata like rock walls and floating surfaces like docks with low current velocity, while mat-like colonies are common on rocky seabeds where the currents are strong.

Colonies can grow at depths ranging from <1m to at least 81m. Colonies also tend to cover >50% of the available space at most locations where it is found. However, colonies commonly overgrow other invertebrates. *Didemnum* sp. A's mat-like morphology may smother infauna, as well. (Bullard et al. 2007).

Potential predators may be chitons, sea stars, sea urchins and the common periwinkle *Littorina littorea*. (USDA 2003)

Didemnum sp. A temperature tolerances remain unclear, but its current distribution suggests that it is a temperate species, surviving subtidally in water temperatures as low as -2ºC, but also growing well at temperatures in excess of 24ºC. (Bullard et al. 2007)

II. PATHWAY INFORMATION (include references):

It has been suggested that *Didemnum* sp. A underwent range expansions due to human-mediated transportation, such as the international transport of ascidians on the hulls and in the ballast water of recreational and commercial ships (Bullard et al. 2007, Lambert and Lambert 1998). Because it can grow on shellfish and in deeper waters that are fished heavily, the seafood industry and research facilities might also be considered vectors. Ocean currents may also play a role, in more localized range expansions.

III. RATING ELEMENTS: Rate statements as low, medium, or high.

Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Didemnid species are found all over the world, including France, New Zealand, Europe, and now the United States. Given the frequency of occurrence, high rates of international trade and fishing, there is a very high probability that the organism is in the pathway. (G)

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

The basic understanding of the ecology and physiology of *Didemnum* sp. A is limited, but given observations of its depth distribution and survival in extreme temperatures, it would most likely survive in transit (Bullard et al. 2007).

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

The understanding of *Didemnum* sp. A's ecology is still limited. However, observations show that the ascidian is a strong spatial competitor and rapid colonizer. These are two traits that would make it a successful invader capable of successfully colonizing and maintaining a population where introduced. (Bullard et al. 2007). Additionally, several other species in the didemnid group have chemical defenses, which are particularly deterrent to potential predators (Vevoort et al. 1998, Pisut and Pawlik 2002). Most didemnids also have a very low surface pH that deters feeding by generalist fish predators (Pisut and Pawlik 2002).

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Didemnum sp. A is an aggressive and rapidly spreading nonindigenous colonial ascidian that has become established on the east and west coasts of North America, approximately over the past 10-20 years. Initial populations were isolated and small (in the 1980s and possibly the 1970s), but during the 1990s, the species began a rapid population expansion and it is now a dominant member of many subtidal communities on both coasts (Carman and Roscoe 2003). It currently seems to be undergoing a rapid worldwide expansion (as reviewed in Bullard et al. 2007). This may,however, be due to the heightened awareness of the species, and the increased number of surveys targeting this species.

CONSEQUENCE OF ESTABLISHMENT

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

The establishment of *Didemnum* sp. A could have direct negative effects on aquaculture and fishing industries. Colonies completely overgrow a number of invertebrates, including shellfish- colonies completely overgrow siphons of epifaunal and infaunal bivalves, leading to their death. At sites where colonies blanket large areas of the seafloor, its morphology may smother infauna, reducing food supply for bottom-feeding fishes and indirectly increasing the risk of predation for shelter-seeking fishes. This may result in the direct mortality of commercially important fish species. (Bullard et al. 2007) In addition, cage culture facilities and marinas might expect economic losses as a result of increased labor necessary to remove the colonies from cages, docks, and vessels.

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Environmental impacts resulting from the establishment of *Didemnum* sp. A include death of a variety of species as a result of overgrowth by the ascidian, i.e. macroalgae, hydroids, anemones, bryozoans, scallops, mussels, tubiculous polychaetes, and crustaceans that have completed their terminal molt. This would directly reduce the amount of food available to bottom feeders, and could result in reduced biomass at the next trophic level. *Didemnum* sp. A also inhibits the settlement of other organisms. By both smothering and inhibiting recruitment, it could become the dominant member of the invaded community, reducing biodiversity or causing other significant changes in benthic community structure (Bullard et al. submitted, Whitlatch et al. 1995).

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = MC

The major impact expected to result from *Didemnum* sp. A is in aquaculture. See description above.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

This analysis identifies *Didemnum* sp. A as an organism of major concern. Mitigation is justified.

V. SPECIFIC MANAGEMENT QUESTIONS:

- Can methods be developed to eradicate *Didemnum* sp. A?
- Can methods be developed to control *Didemnum* sp. A?
- Are there any anti-fouling substrates that are successful in the prevention of settlement of *Didemnum* sp. A? Can these substrates be used in the aquaculture industry?

VI. RECOMMENDATIONS:

- It is recommended that there is continual support for research studies investigating *Didemnum* sp. A's physical tolerances, life history characteristics, and ecological interactions, i.e. potential predators and competitive abilities relative to other species) so that its specific impacts on marine communities may be assessed.
- Studies of particular importance should be those that investigate the asexual fragmentation that occurs in *Didemnum* sp. A's dispersal, since initial observations indicate that fragments of adult colonies likely have higher survivorship, and thus greater transport potential, than short-lived non-feeding larvae. The transportation of fragments in ballast water could explain the species' highly disjunct distribution, and may assist in further expansion of its range.
- It is also recommended that there is continual support for studies investigating the true taxonomy of the species. Are there two species of *Didemnum*? If so, are both established in Long Island Sound?

VII. MAJOR REFERENCES:

Bullard SG, Lambert G, Carman MR, Byrnes J, Whitlatch RB, Ruiz G, Miller RJ, Harris L, Valentine PC, Collie JS, Pederson J, McNaught DC, Cohen AN, Asch RG, Dijkstra J, Heinonen K. (2007) The invasive colonial ascidian *Didemnum* sp. A: current distribution, basic biology, and potential threat to marine communities of the northeast and west coasts of North America. *Journal of Experimental Marine Biology and Ecology.* 342: 99-108.

Lambert CC and Lambert G. (1998) Non-indigenous ascidians in southern California harbors and marinas. *Marine Biology*. 130: 675-688.

Pisut DP, Pawlik JR. (2002) Anti-predatory chemical defenses of ascidians: secondary metabolites or inorganic acids? *Journal of Experimental Marine Biology and Ecology*. 270: 203-214.

US Department of Agriculture. (2003) Integrated Taxonomic Information System on-line Database. http://www.itis.usda.gov. internet accessed: October 6, 2005.

Vevoort HC, Pawlik JR, Fenical W. (1998) Chemical defense of the Caribbean ascidian *Didemnum conchyliatum*. *Marine Ecology Progress Series*.
164: 221-228.

Whitlatch RB, Osman RW, Frese A, Malatesta R, Mitchell P, Sedgwick L. (1995) The ecology of two introduced marine ascidians and their effects on epifaunal organisms in Long Island Sound. In: Balcolm N. (ed.) Northeast conference on nonindigenous aquatic species. Connecticut Sea Grant College Program, Publication no. CT-SG-9504, pp 29-48.

The next set of risk analyses are, again, presented in the format designed by Orr (1995). The following assessments represent a subset eight organisms that are potentially invasive to Connecticut's marine waters, which are part of Long Island Sound. Identification of organisms that are potentially invasive and the risk associated with them enables scientists and managers alike to work together to develop proactive approaches for prevention of establishment. Where prevention is impossible, these analyses will aid in the development of the correct risk management steps needed reduce the impact of the introduced species on Connecticut's marine environment.

3. Risk Assessment for the Chinese mitten crab *Eriocher sinensis*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM *Eriocher sinensis* **FILE NO.** 3
ANALYST Kari Heinonen **DATE** 10/27/2005
PATHWAY Private citizen release to establish populations for harvest, ballast water, larval dispersal, short distances over land, aquaculture
ORIGIN China, eastern Asia

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

Life Cycle/Life History: *Eriocher sinensis* is a catadromous crab, with a lifespan of 2-5 years. Carapace width of adults averages 70-80mm, but can attain a maximum size of 100mm. The crab rears primarily in freshwater habitats for 2-3 years and spends most of its adult life in freshwater, before it migrates to estuarine/marine habitats to reproduce. *Eriocheir sinensis* requires a minimum salinity of 15 ‰ for its eggs to develop (Josefsson and Andersson 2001). Each summer, adult mitten crabs release vast quantities of larvae (250,000-1 million eggs) in estuarine waters (Normant et al. 2000, Washington Sea Grant 2005). Larval development consists of 6 larval stages lasting approximately 90 days. Adults produce one or two broods during their lifespan (Herborg et al. 2003).

Mitten crabs are also agile in their movement over land. During the upstream migration of juveniles from estuaries, mitten crabs can reach rivers, lakes, and ponds as far as 1200km from the coast (Herborg et al. 2003).

Distribution: The Chinese mitten crab first appeared as an invasive species in Germany during the early 1900s and has since spread through most of Europe, and is now in the United States. It has been reported from Lake Eerie, San Francisco Bay, the Columbia River, and Mississippi Sound. It has also been sighted in New York, which borders and shares a body of water with Connecticut.

Natural History: Chinese mitten crab has two other aliases, i.e. hairy-fisted crab or woolly-handed crab. *Eriocher sinensis* originates from the Far East (22ºN) to the border with North Korea (40ºN). The mitten crab is common in inland freshwaters, shallow coastal waters, and in deep-sea waters as well (Normant et al. 2000). The mitten crab attains a relatively large maximum size and adults have few natural enemies in other areas of the world where it has invaded, i.e. Poland (Normant et al. 2000). It is described as an opportunistic omnivore, i.e. juveniles eat mostly vegetation like filamentous algae, *Potamogeton, Elodea, Lemna*). During somatic growth, their diet broadens to include small invertebrates (tubificids, mollusks, amphipods, chironomids, Polychaeta, Coeloptera, and Daphnia), salmonid eggs, and individuals will also feed on mosquito larvae (Zhang et al. 2003, Paunovic et al. 2004). Likely predators include sturgeons, striped bass, channel catfish, bullfrogs, raccoons, river otters, and wading birds (Washington Sea Grant 2005).

III. PATHWAY INFORMATION (include references):

The species was initially introduced by an individual for harvest. The species which spreads naturally by larval dispersal in the water, and by adult migration over land for short periods, can also be transported in ship's ballast water (O'Neill and MacNeill 2005). For example, estuarine water containing mitten crab larvae can be carried to distant locations in the ballast water of ocean-going vessels (Draheim 1998). While the most likely vector is human-aided transportation (i.e. ballast water), transport of the mitten crab may be associated with intensive oyster aquaculture (Herborg et al. 2003).

III. RATING ELEMENTS: Rate statements as low, medium, or high. Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

<u>PROBABILITY OF ESTABLISHMENT</u>

Estimate probability of the nonindigenous organism being on, with, or in the pathway.

(Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

It is highly likely that *E. sinensis* is in the pathway. Estuaries often serve as ports of call where the shipping traffic is heavy. More localized dispersal is also highly likely, as individuals can cross land (potentially from one catchment to another). If the two waterways diverge, the crab's chances for expanding its range increase. Some specimens in empty "shells" of cirripeds have been reported on ship hulls. Fouling communities are typically composed of encrusting or sessile species, however they can include mobile species. This vector can introduce species through a variety of means. Likewise, the mitten crab is an Asian delicacy and live crabs have been illegally imported to Asian markets.

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

It is also highly likely that *E. sinensis* would survive in transit. Mesh size on the intake for ballast are large enough to allow larvae and juveniles to pass through the screen. Additionally, the larval stage lasts for approximately 90 days in water with a salinity of at least 15 ‰. Given the crabs long larval duration and tolerance to a wide range of physical conditions, there is a high probability that the organism would survive. Moreover, those persons transporting mitten crabs to sell as a delicacy in the Asian marketplace will likely make extra efforts to ensure that the crabs are alive upon arrival.

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Eriocheir sinensis has successfully colonized and maintained populations all over the world. It has been named one of the world's worst 100 invaders (IUCN). Because of similarities between native and invaded regions, it would have sufficient habitat and prey items to guarantee survival and reproduction. *Eriocheir sinensis* tolerates a wide range of abiotic factors. All three regions of the world in which *E. sinensis* occur exhibit a temperate climate; however, the temperature range mitten crabs encounter within these regions is vast, and laboratory studies underscore the crab's ability to tolerate a wide range of temperatures. The Chinese mitten crab has exhibited a remarkable ability to survive in highly modified aquatic habitats, as it encounters highly altered and polluted waters in many parts of its native and introduced ranges.

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Control of this species will be difficult because of its abundance, ubiquity, high reproductive rate, and wide range of physiological tolerances. Because it is transported both naturally and by humans, even state and federal regulations will not prevent expansion. As stated above: 'More localized dispersal is also highly likely, as individuals can cross land (potentially from one catchment to another). If the two waterways diverge, the crab's chances for expanding its range increases. Therefore, the probability of the mitten crab spreading beyond the colonized area is high.

CONSEQUENCE OF ESTABLISHMENT

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Because of their scavenging nature, the crabs may threaten the recreational and commercial fishing industry (esp. shrimping; Herborg et al. 2003) in estuaries by robbing bait off fish hooks and fish traps, damaging fish nets, and injuring netted fish. They have also been known to easily clog fishing gear and water intakes. (O'Neill and MacNeill 2005, Ray 2005) The high abundance of this crab has already caused great economic impacts on fish salvage operations of State and Federal water pumping facilities in California (Culver and Walter 2005). The crab may also cause disturbance to human activities and structures as large numbers of crabs migrate over and around dams, through city streets, and into intake pipes by the thousands (Draheim 1998). In California, mitten crabs have been found on roads, airport runways, parking lots, yards, and swimming pools (Washington Sea Grant 2005). Removal of individuals is a nuisance, but may also cost money (i.e., removal from runways delays flights and costs money).

Despite efforts to reduce the impact of E. sinensis, the species is still spreading across the globe. It was calculated that the monetary impact caused by this invader in German waters totals to approximately 80 million Euro since 1912 (Herborg et al. 2005).

However, a market for the crab does exist. *Eriocher sinensis* has been used as bait for eel fishing, to produce fish meal, cosmetic products and as fertilizer in agriculture. The Chinese mitten crab supports a $1.25 billion per annum aquaculture industry in China (Herborg *et al.* 2005)

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

The crabs reproduce rapidly and form extensive burrows in riverbanks and levees, posing a direct threat to earthen water control structures that could potentially lead to erosion (O'Neill and MacNeill 2005, Ray 2005). In tidal regions the crabs usually burrow into beach zones between the high and low mark; these burrows can be 50cm deep (Normant and Chrobak 2002). In tideless areas, burrowing activity is less extensive.

Most ecological impacts are linked to disturbance of existing communities of and populations of estuarine and freshwater organisms through competition and predation (Draheim 1998). For example, *E. sinensis* competes with fish and invertebrates (i.e. crayfish spp.; Herborg et al. 2003) for food (O'Neill and MacNeill 2005). It has been shown to reduce native populations in some areas and alter the benthic community structure. In contrast, it has also been shown to increase biodiversity in the Gulf of Gdansk (Normant et al. 2002)

U.S Fish and Wildlife Service listed *E. sinensis* as an 'injurious species', making their importation, capture, and possession a serious crime (Draheim 1998). This is based upon the potential threat to indigenous wildlife, aquatic life, or habitat.

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = MC

In Asia, *E. sinensis* is an intermediate host for the Oriental lung fluke, a parasite that can be contracted through the consumption of raw or undercooked crab meat. Human infestation by this fluke can cause sometimes-fatal tuberculosis-like symptoms. Because mitten crabs are considered a delicacy, this invasion may also pose a threat to human health. (Draheim 1998). The crabs also bioaccumulate heavy metals, such as mercury and lead, which can be passed along to potential predators, causing burdens of these contaminants to increase up the food web, which includes humans (O'Neill and MacNeill 2005).

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

V. SPECIFIC MANAGEMENT QUESTIONS:

- Are monitoring stations set up to identify successful establishment of the crab in Connecticut? Have educational materials been distributed so that scientists, educators, stakeholders, and the general public can identify the species?

- Is Connecticut inhabited by necessary hosts for the lung fluke (e.g. snails)? If all necessary hosts are present, then an infestation is more possible than if they were absent.

- What resident species are expected to be impacted by the invasion of the mitten crab and what is their current population status?

- Is there a market for Chinese mitten crabs in Connecticut, i.e. in the food industry or as fertilizer?

VI. RECOMMENDATIONS:

- Decreasing the amount of shipping traffic and regulating the release of ballast water will likely decrease the opportunity for release of the mitten crab into Connecticut waterways.

- Eradication of the species should be investigated. Shan et al. (2003) found that fipronil is successful in killing the crabs, but it can be deadly to other non-target aquatic organisms as well.

- Passive trapping systems (i.e., Culver and Walter 2005) should be investigated as means for removal of the crab. Such a system would take advantage of the catadramous lifestyle of the crab, and remove individuals during migration/before releasing eggs/larvae.

- Perhaps most important is monitoring for established populations of *E. sinensis* in Connecticut waterways, and nearby regions in Long Island Sound, as well as regions North and South of the Sound.

- Develop a market for the crab: Crabs have been used as bait for eel fishing, to produce fish meal, cosmetic products and as fertilizer in agriculture. The Chinese mitten crab supports a $1.25 billion per annum aquaculture industry in China (Herborg *et al.* 2005) This could provide an effective mean for control.

VII. MAJOR REFERENCES:

Culver, C.S. and M. H. Walter. 2005. Prospective Management of the Chinese mitten Crab: Evaluation of a passive trapping system. Abstract. University of California, Santa Barbara, California.

Draheim, R. (1998) Chinese Mitten Crab: A threat to Washington State Waters? Puget Sound notes. **41**: 7.

Herborg, L-M., S.P. Rushton, A.S. Clare, M.G. Bentley. 2003. Spread of the Chinese mitten crab (*Eriocheir sinensis* H. Milne Edwards) in Continental Europe: analyses of a historical data set. *Hydrobiologia*. **503**: 21-28.

Josefsson, M. and B. Andersson. (2001) The Environmental Consequences of Alien Species in the Swedish Lakes Mälaren, Hjälmaren, Vänern and Vättern. Ambio. **30**: 514-521.

Normant, M., A. Wiszniewski, A. Szaniawska. 2000. The Chinese Mitten Crab *Eriocheir sinensis* (Decapoda: Grapsidae) from Polish Waters. Oceanologia. **42 (3):** 375-383.

Normant, M. and M. Chrobak. 2002. The Chinese Mitten Crab *Eriocheir sinensis*- an immigrant from Asia in the Gulf of Gdansk. Oceanologia. **44:** 123-125.

O'Neill, C. and D. MacNeill. 2005. NYSG Educating River Residents Regarding Potential for Invasive Species New to Northeast; Enlist Aid in Spotting Chinese Mitten Crab. On-line access.

Paunovic, M., P. Cakic, A. Hegedis, J. Kolarevic. 2004. A report of *Eriocheir sinensis* (H. Milne Edwards, 1854) [Crustacea: Brachyura; Grapsidae] from the Serbian part of the Danube River. Hydrobiologia. **529:** 275-277.

Ray, G. 2005. Invasive Marine and Estuarine Animals of the South Atlantic and Puerto Rico. ANSRP Technical Notes Collection (ERDC TN-ANSRP-05-5). U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://el.erdc.usace.army.mil/ansrp

Shan, Z, L. Wang, D. Cai, R. Gong, Z. Zhu, and F. Yu. (2003) Impact of fipronil on crustacean aquatic organisms in a paddy field-fishpond ecosystem. Bulletin of Enivronmental Contamination and Toxicology.

Washington Sea Grant. 2005. Non-indigenous Species Fact Sheet: Chinese Mitten Crab. http://www.wsg.washington.edu/outreach/mas/nis/mittencrab.html

Zhang, S, H. Jin, Y. Feng, L. Zhang, J. Lv. 2003. Feeding ecology of Eriocheir sinensis, Procambrus clarkia and Monopterus albus. Acta hydrobiologica sinica. **27:** 496-501.

4. Risk Assessment for Wakame, *Undaria pinnatifida*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM *Undaria pinnatifida* **FILE NO.** 4
ANALYST Kari Heinonen **DATE** 11/04/2005
PATHWAY Hull cleaning, ballast water, aquaculture transportation
ORIGIN China, eastern Asia

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

Life Cycle: *Undaria*'s life cycle consists of both a macroscopic stage (sporophye) and a microscopic stage (gametophyte). The sporophytic stage is usually present during warmer months, and the gametophytic stage is usually present during colder months. In native ranges, *Undaria* exhibits an annual cycle and sporophytes disappear seasonally. In contrast, some invasive populations exhibit sporophytes year-round. Sporophylls on mature sporophytes produce millions of spores with motile periods of up to 5 hours. These spores often colonize floating objects. Spores eventually germinate into gametophytes which can lay dormant for up to 3 years. Sporophytes can maintain populations under salinities of 20-34 ‰ and temperatures ranging from 0-27ºC. (as reviewed by Murray et al. 2004)

Distribution: While its native range includes Japan, Korea, and China, *U. pinnatifida* has been accidentally introduced to Australia, New Zealand, Tasmania, and the Mediterranean Sea (France, Italy). It was deliberately introduced into the North Atlantic, to Brittany for commercial exploitation, then was recorded in natural communities in France, Britain, Spain and Argentina. It is also found along the west coast of North America, i.e. California and Baja, Mexico. (Murray et al. 2004, Global Invasive Species Database 2005, personal communication with Charlie Yarish)

Natural History: *Undaria* is a large brown kelp, also known as Asian kelp, apron ribbon vegetable, wakame, and miyeuk. It has been cultivated since the late 1950s in its native range. Fronds can reach lengths 1-3m long. *Undaria* can grow from the low intertidal to 25m depths, in a variety of habitats, ranging from silty harbor waters to open coasts with a wide range of wave exposures. *Undaria* can colonize most hard surfaces including artificial substrata (e.g. ropes, buoys, hulls, bottles, floating pontoons, and plastic), as well as natural substrata (e.g. stable rocky reefs, mobile cobble habitats, shells in soft sediments, seagrass, and epiphytically on seaweeds). Temperature tolerances (see above) may vary in different geographical locations. Polluted waters may be an advantage in the spread of this species because it can colonize sewage-influenced habitats. (as reviewed by Murray et al. 2004) It is one of two seaweeds on the "100 of the World's worst Invasive Alien Species" list (Trowbridge XXXX). Grazers include the kelp crab *Pugettia producta* (Thornber et al. 2004)

II. PATHWAY INFORMATION (include references):

Undaria has been introduced intentionally for cultivation for human consumption, but it has also been introduced accidentally. For example, translocation of *Undaria* through aquaculture and fisheries activities (e.g. oyster trade), release of the species in ballast water discharged from vessels (e.g., various types and life stages of species can be transported in ballast water), and hull fouling.
Hull fouling can introduce species through a variety of means. Three examples are: (1) The spawning of a fouling species on a vessel in port (2) The dislodgement of fouling species

from a vessel in port and (3) The sinking of fouled vessels either deliberately or accidentally can introduce new species to a location. (as reviewed by Murray et al. 2004).

III. RATING ELEMENTS: Rate statements as low, medium, or high.

Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Because *Undaria* can grow on any hard surface including artificial substrates, it can be easily and accidentially introduced to a new location. In addition, natural dispersal occurs following the release of motile spores from the sporophyte. The distance over which spores travel before settling will largely be determined by their viability and behaviour and the speed of ambient water currents, but it can extend from hundreds of meters to several kilometers. (GISD 2005) Therefore, *Undaria* could easily be taken up in ballast water, attached to the hull of a ship, attached the shell of an oyster being shipped for aquaculture, or intentionally used for food. Given the number of possible vectors and the frequency with which each one probably occurs, it is highly likely that the organism is in the pathway.

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Because gametophytes of *Undaria* can lie dormant for up to 5 years (personal communication with Charlie Yarish), it is entirely possible that the organism (in correct form) could survive in transit and become viable under the conditions in its introduced range.

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Undaria possesses 5 characteristics that make it a highly successful invader. It is an opportunistic weed that rapidly colonizes new or disturbed substrata and artificial floating structures. It occurs in dense fronds on benthic shores that form thick canopies. It colonizes a wide range of shores that vary in wave exposure and depth. It thrives over an extensive vertical distribution from low tide level to 25m. Finally, it has an extended period of spore formation and release that are present year round. Because introduced individuals are larger size, have longer reproductive periods, and are able to tolerate a wide range of environmental conditions compared to that of native populations, it is highly likely that

Undaria will not only successfully colonize and maintain populations where it is introduced, it will probably be a competitor to native algal species. (as reviewed by Muuray et al. 2004)

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

It has been predicted that coastal boating traffic would be the means of the significant spread of this species (as reviewed by JNCC 1997). If shipping/boat traffic is heavy in certain coastal areas, there is a higher probability that *Undaria* would spread beyond the colonized area. The probability of Wakame to spread beyond the colonized area might also be dependent upon the frequency of oyster/shellfish trade.

CONSEQUENCE OF ESTABLISHMENT

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Wakame is sold commercially for its food value in its countries of origin. It is added to miso soup for texture and flavor. It is harvested from both natural and cultivated populations and provides a significant commercial enterprise (Murray et al. 2004). In contrast, wakame has the potential to become a problem for marine farms by increasing labour and harvesting costs due to fouling problems on fin fish cages, oyster racks, scallop bags and mussel ropes. Heavy fouling may also restrict water flow through cages.
Undaria could also foul mussel farms, salmon farms and boats. Heavy infestations of *Undaria* may also clog marine farming machinery, slow growth of mussels and restrict water circulation. Heavy fouling of boats seriously decreases their efficiency.

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

The impacts of *Undaria pinnatifida* are not well understood and are likely to vary considerably depending on the location. *Undaria* can change the structure of ecosystems, especially in areas where native seaweeds are absent, due to its opportunistic behavior (GISD 2005). It may also cause the displacement of other native species (JNCC 1997). In Connecticut waters, it has been suggested that it will compete with and possibly replace the native kelp species, *Laminaria*, which is a food and habitat resource for many native faunal species.

The canopies formed by *Undaria* may shade understory species, or increase biodiversity by providing shelter and food to other species (Trowbridge XXXX). Despite the fact that the development of mono-specific *Undaria* stands is considered a threat to natural ecosystems; Forrest and Taylor (2002) found no evidence of significant ecological impacts from the invasion of *Undaria*. It may also provide a food source for native grazers, like crabs and urchins (Edgar et al. 2004, Thornber et al. 2004)

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

It has been suggested that possible effects of *Undaria* on food chains in Connecticut's marine waters may pose the most serious threat to the public, i.e. it may replace native food and habitat resources for organisms that humans rely on. If *Undaria* does shade aquaculture cages, then the quantity of shellfish available in the markets may decline.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

V. SPECIFIC MANAGEMENT QUESTIONS:

- Besides shading and opportunistic expansion, what are the ecological impacts on *Undaria*? What effects will these impacts have on the Connecticut coastline and nearshore waters?

- What available resources does Connecticut have in the event of successful establishment, and the need for eradication?

- Are monitoring projects set up to track initial invasion and long-term impacts?

VI. RECOMMENDATIONS:

- It is recommended that various habitats and sentinel sites within CT are monitored continuously to document establishment. It has been suggested that these sites be similar to Millstone, some with warm temperatures and some with cool temperatures.

- It is also recommended that research investigating the impacts of *Undaria* on native ecosystems is continued, so that appropriate management plans can be implemented for specific geographic locations.

- Vessel traffic and ballast water, as well as the aquaculture industry, should also be monitored for future introductions.

- It is recommended that in the event of introduction *Undaria* be removed from ship hulls (e.g, cutting and scraping using SCUBA). Because larger individuals release more zoospores, management efforts involving manual removal should concentrate on removal of large sporophytes in the interest of time and money (Schaffelke 2005). However, manual removal involves labor and equipment, and results show that it is only somewhat effective (Murray et al. 2004). Because the species has a value as food for human consumption, removed thalli could be sold to generate revenue. Heat and blow-torch methods could also be used to remove individuals from the hull, but leave no product to generate revenue.

VII. MAJOR REFERENCES:

Edgar, G.J., N.S. Barrett, A.J. Morton, C.R. Samson. 2004. Effects of algal canopy clearance on plant, fish, and macroinvertebrate communities on eastern Tasmanian reefs. Journal of Experimental Marine Biology and Ecology. **312**: 67-87.

Forrest, B.M. and M. D. Taylor. 2002. Assessing invasion impact: survey design considerations and implications for management of an invasive marine plant. Biological Invasions. **4**: 375-386.

Global Invasive Species Database. 2005. http://www.issg.org/database/species/ecology

Joint Nature Conservation Committee. 2004. N.C. Eno, R.A. Clark, W.G. Sanderson (eds.) Non-native marine species in British waters; a review and directory.

Murray S.N., L. Fernandez, J.A. Zertuche-Gonzalez. 2004. Status, Environmental Threats, and Policy Considerations for Invasive Seaweeds for the Pacific Coast of North America. DRAFT- from Yarish- 2005.

Schaffelke, B., M.L. Campbell, C.L. Hewitt. 2005. Reproductive phenology of the introduced kelp *Undaria pinnatifida*. Phycologia. **44:**84-94.

Thornber, C.S., B.P. Kinlan, M.H. Graham, J.J. Stachowicz. 2004. Population ecology of the invasive kelp *Undaria pinnatifida* in California: environmental and biological controls on demography. Marine Ecology Progress Series. **268**: 69-80.

Trowbridge, C. (XXXX) A global proliferation of non-native marine and brackish macroalgae. From Yarish

5. Risk Assessment for the red alga *Grateloupia turuturu*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM	*Grateloupia turuturu*	**FILE NO.**	5
ANALYST	Kari Heinonen	**DATE**	11/22/2005
PATHWAY	Hull fouling, oyster mariculture	**ORIGIN**	Western Pacific Ocean

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

Life Cycle/Life History: The species exhibits a distinct seasonal pattern in its invaded habitat, with low percent cover in May-June and high percent cover in October (Harlin and Villalard-Bohnsack 2001). New blades appear year-round. Blade color also changes seasonally: light red in summer, dark burgundy over winter, and yellow-red in Spring. Increase in color saturation seems to correlate with an increase in nutrient (nitrogen) concentration (personal communication with Charles Yarish). Spores often develop into crusts and then blades and filaments. However, filaments and/or crusts also produce new crusts, new blades also develop from old crusts, and blades can also regenerate from old damaged blades (Harlin and Villalard-Bohnsack 2001). The species has a very high growth rate, with juvenile blades growing to 25 cm over 3-4 months. A single plant can attain sizes over 1.5-2 m. Not only does this species grow rapidly, but it also recruits rapidly to new spaces, i.e. 300 new blades in one months time (Harlin and Villalard-Bohnsack 2001).

Distribution: It occurs in England, Portugal, Spain, France and NW Atlantic (Trowbridge XXXX, personal communication with C. Yarish). It was discovered in Narragansett Bay, RI in 1994 (Harlin and Villalard-Bohnsack 2001) and was reported in CT, Long Island Sound in 2004 (CT Sea Grant 2005).

Natural History: The red alga has been described as *Grateloupia doryphora* in the past. Comparative rbcL sequence analysis and morphology suggest that it is actually *G. turuturu* (Gavio and Fredericq 2002). It is a large, red foliose algae (Florideophycae). In Narragansett Bay, the size and shape of *G. turuturu* varies with latitudinal and vertical position (Harlin and Villalard-Bohnsack 2001). In adverse conditions, most thalli exist in their reduced perennating crustose form. The species mainly grows on hard surfaces, which include coralline algae.

The crust form of most algae is more resistant to herbivory, and blades are more productive (Lubchenco and Cubit 1980, Littler and Arnold 1982). Findings of herbivory experiments using limpets and *G. turuturu* are consistent with this idea (Harlin and Villalard-Bohnsack 2001).

Little is known about this species because it has not been well-studied.

II. PATHWAY INFORMATION (include references):

III. RATING ELEMENTS: Rate statements as low, medium, or high.

Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Due to the life cycle of *G. turuturu*, it is highly likely that the organism could be on the pathway. Spores could be carried in ballast water, the organism could be attached to the hull of a ship, rock, or shell (e.g., transportation in aquacultural trade), or it could be transported directly by humans.

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

High turbidity and competition with other macroalgal species are the only known environmental/ecological conditions under which the dispersal/survival of the organism would be limited. Therefore, it is entirely possible that the organism would survive in transit, and has already survived the transoceanic transit from Asia, Britain, or France.

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H

Uncertainty Code (VC-VU) = VC

Farnham (1980) shows that the organism does not thrive in areas of high turbidity or high levels of competition with native sublittoral algae. However, *G. turuturu* thrives under the following conditions: 1) lack of grazers, (2) high levels of nutrients in the water. In addition, the species is a good invader because of the following characteristics: (1) tolerance to lowered salinities and elevated seawater temperatures in the summer, (2) rapid growth to 100% coverage, and (3) multiple recruitment strategies (JNCC 1997, Trowbridge XXXX). The organism has already been discovered off the coast of Connecticut in 2004 (Millstone Environmental Lab., pers comm).

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

It is probable that the organism will spread beyond the colonized area, though the rate at which it will expand its range is unknown. In British waters, it has spread slowly through marginal, but natural dispersal (up to 30 miles). This is credited to movement of plants attached to small stones (JNCC 1997). Because water turbidity and competition with indigenous sublittoral algae most likely inhibit development in the sublittoral, it may be the case that such factors would stifle the spread of the species. In contrast, the population of *G. turuturu* along the Rhode Island coast has spread rapidly from Narragansett Bay to Rhode Island Sound and adjacent waters since its appearance in 1994 (Harlin and Villalard-Bohnsack 2001). Two factors that might aid in the spread of the species are the capacity to produce plants from portions of blades, and the crustose form can be disseminated by shellfish.

<u>CONSEQUENCE OF ESTABLISHMENT</u>

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = L
Uncertainty Code (VC-VU) = MC

The economic impact of the organism is largely unknown, due to the lack of studies performed on *G. turuturu*. However, it is used for low levels of human consumption and as a source of carageenan in the Pacific (Trowbridge XXXX).

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = MC

Most of the effects of *Grateloupia turuturu* on other species are not yet known (Harlin and Villlalard-Bohnsack 2001), due to insufficient ecological study of the organism. However, it may be competing with the Irish moss *Chondrus crispus* on NW Atlantic shores (Trowbridge XXXX). Because of its growth to 100% cover in some areas (e.g., RI), it is suggested that there may be an associated shift in the accompanying macroalgal species over time (Harlin and Villalard-Bohnsack 2001).

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = MC

Because little is known about the species, it is difficult to estimate any type of impact from social or political influences. Given what little knowledge is available, one might suggest that if *G. turuturu* does replace *C. crispus* as a native keystone species, it will indirectly affect coastal fisheries. *Chondrus* is a food source for many coastal faunal species. If there is a decline in this level of productivity, one would expect similar biomass declines to be reflected at higher levels of the food web.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

V. SPECIFIC MANAGEMENT QUESTIONS:

- Besides shading and opportunistic expansion, what are the ecological impacts on *Grateloupia*? What effects will these impacts have on the Connecticut coastline and nearshore waters?
- What available resources does Connecticut have in the event of successful establishment, and the need for eradication?
- Are monitoring projects set up to track initial invasion and long-term impacts?

VI. RECOMMENDATIONS:

- Since the organism has already been discovered in CT, it is strongly recommended that a monitoring plan be established in order to document the spread of the organism into additional sites.
- Due to the lack of scientific literature on the ecological impacts of this organism, it is also strongly recommended that research efforts investigating its effects be continued so that appropriate management schemes can be implemented..
- Individuals at local mariculture facilities should be made aware of the physical characteristics of the organism so that they do not accidentally transport the algae, and ship traffic should be monitored as well.

VII. MAJOR REFERENCES:

Farnham, W.F. (1980) Studies on aliens in the marine flora of Southern England. In: *The shore environment, volume 2: ecosystems*. (eds.) Price, J.H., Irvine D.E.G., W.F. Farnham. London: Academic Press. Pp. 875-914.

Gavio, B. and S. Fredericq. *Grateloupia turuturu* (Halymeniaceae; Rhodophyta) is the correct name of the non-native species in the Atlantic known as *Grateloupia doryphora*. *European Journal of Phycology.* **37:** 349-359.

Harlin, M.M. and M. Villalard-Bohnsack. (2001) Seasonal dynamics and recruitment strategies of the invasive seaweed *Grateloupia doryphora* (Halymaeniaceae, Rhodophyta) in Narragansett Bay and Rhode Island Sound, Rhode Island, USA. *Phycologia.* **40**: 468-474.

Joint Nature Conservation Committee. 1997. Non-native marine species in British waters: a review and directory. (eds.) Eno, N.C., R.A. Clark, W.G. Sanderson. Peterborough. 135 pp.

Trowbridge, C. (XXXX) *A global proliferation of non-native marine and brackish macroalgae.* 70 pp.

6. Risk Assessment for the brown alga *Sargassum muticum*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM	*Sargassum muticum*	**FILE NO.**	6
ANALYST	Kari Heinonen	**DATE**	12/02/2005
PATHWAY	See below	**ORIGIN**	Asia

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

Life Cycle/Life History: *Sargassum muticum* is self-fertile. Even though it is a perennial, its fronds senesce in early fall and only the basal holdfast overwinters in an inactive state. In early spring, each holdfast produces numerous fronds which can grow 3m or more. Receptacles, housing the oogonia and the antheridia, are based along the frond. Eggs released from the oogonia are released and attach to the external receptacle, where they are fertilized. Fertilized eggs develop into rhizoids (that are heavy and sink fast), which are subsequently released and recruit to substrate in close proximity to the parent plant. (GISD 2005) The growth form of *S. muticum* is modular: A plant is attached to the substratum by a perennial holdfast that gives rise to a single stem. Every year, several apically extending main branches emerge from the stem and produce secondary branches, which in turn may give rise to higher-order branches (GISD 2005).

Distribution: *Sargassum muticum* is found in coastland, estuarine, and marine habitats (GISD 2005). Its known introduced range includes Europe and North America, in the Northeast Atlantic and the Mediterranean Sea (Murray et al. 2004). It is common on the west coast of the United States, British Columbia, Mexico, and Hawaii (Trowbridge XXXX). Currently, it has not been discovered in Connecticut.

Natural History: *Sargassum muticum* is alarge brown algae whose stem has regularly alternating branches with flattened oval blades and spherical gas bladders. It is highly distinctive and olive-brown in color. It can grow intertidally and subtidally on a wide variety of substrates, including rock, broken shells, and mud. It grows in a variety of habitats that are subject to both wide ranges of light and wave exposure. Despite the fact that its temperature range is 10 to 30ºC, it survives at temperatures close to 0°C. It tolerates salinities ranging from 6‰ to 34‰. However, it is found to grow mostly in relatively sheltered areas in its native range and has a high tolerance for polluted waters. (as reviewed by Murray et al. 2004) In Pacific North America, it is very common and abundant in shallow, rocky subtidal habitats, i.e. it occurs in densities as high as 126 plants/m².

II. PATHWAY INFORMATION (include references):
The known pathways for *Sargassum muticum* include accidental introduction with shipment of oysters, bait shipping, and self-propelled pathways. The organism can drift, and because it is monecious, self-fertile, and highly fecund, it can become fertile while suspended (GISD 2005).

III. RATING ELEMENTS: Rate statements as low, medium, or high.
Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = RC

While *Sargassum muticum* has invaded areas through oyster trade, it is anticipated to invade areas on the east coast of the United States through the shipping of bait. Spores may also be transported in the ballast water and on ships' hulls (JNCC 1997). However, the most alarming pathway is the organism's ability to drift (JNCC 1997, Murray et al. 2004, GISD 2005).

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Not only will the organism survive in transit, but it will reproduce in transit. The floating fronds that break off of anchored plants do not reattach, but are able to survive for up to 3 months and even become fertile as they float (JNCC 1997, Murray et al. 2004).

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

It is extremely likely that *S. muticum* will successfully colonize and maintain populations if it is introduced to Connecticut. Besides the similarities between its native region and CT, it is highly tolerant of a wide range of physical conditions. Moreover, the organism combines fast growth of branches with the persistence of the perennial holdfast, which reduces interference among any possible neighboring species. This allows *S. muticum* plants to grow in locally dense populations with low mortality and with reduced effects of density on reproduction (GISD 2005). Additionally, the organism can grow to larger sizes outside of its native range, i.e. in Japan it can reach lengths of 1-1.5 m, but in California it can reach lengths of 5-6m, and 10-12m in France (Murray et al. 2004).

Sargassum muticum also exhibits the ability to compensate for eventual canopy losses, further enabling rapid colonization, and consolidation and persistence of local populations, preventing invasion by other species (GIS 2005).

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Drifting plants and branches play a large role in the dispersal of *S. muticum* beyond the initially colonized area. At first, many areas show disjunct populations in bays, accumulating on shores, and then spreading via ocean currents. The dispersal rate of the organism is very high, i.e. 10 km/yr in the Mediterranean, 60 km/yr in the NE Pacific, and 90 km/yr in the NE Atlantic (Murray et al. 2004). For example, the spread of *S. muticum* from England northward to the Netherlands has been attributed to drifting plants (as reviewed by GISD 2005). However, higher temperatures are favorable and will encourage its spread further south, while lower temperatures are unfavorable and will limit its spread north (JNCC 1997).

CONSEQUENCE OF ESTABLISHMENT

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

In terms of economic impact, *Sargassum muticum* is considered a nuisance. The species creates a physical hindrance of small boats with outboard engines less than or equal to 20 hp. It clogs intake pipes of boats and industrial installations. Floating mats of *S.muticum* foul commercial fishing lines and nets, and dense growths on oyster beds make it difficult to observe cultured oysters, with a fear that buoyant fronds will carry oysters out of the culture area or hinder growth and harvesting. Large stands of *S. muticum* are also believed to cause loss in amenity and recreational use of water bodies because they are an "eyesore", give off a pungent odor when rotting on shore, and discourage such water sports as swimming, skiing, sailing, and fishing (GISD 2005).

In contrast, *S. muticum* may be of commercial value to the alginate industry (Trowbridge XXXX).

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = RC

The presence of dense stands of *Sargassum muticum* may affect species diversity of native marine fauna and flora in intertidal pools and the shallow subtidal region (GISD 2005). Once established in a new area, the organism can accumulate high biomass and may therefore be a strong competitor for space and light (Staehr et al. 2000), by prevention of the settlement and development of other algae. The mechanisms by which *S. muticum* would outcompete other species are high recruit densities and fast growth. Irradiance can be reduced by up to 95% in the upper 5cm of a dense canopy, thereby preventing understory algae from development and thriving. In addition, dense stands may dampen flow, increase sedimentation, and reduce ambient nutrient concentrations available for native kelp (e.g., *Laminaria* sp.) and eelgrass species (Murray et al. 2004, as reviewed in GISD 2005). Native canopy (brown algae) and understory (red algae) were more abundant in areas where *S. muticum* had been removed. The native kelp *Laminaria bongardiana* grew more than 2X as fast in plots where the invasive was absent (Britton-Simmons 2004). *Sargassum muticum* settles in spots where the eelgrass *Zoatera marina* has retreated, interfering with regeneration of the bed (Hartog 1997). Because kelp and eelgrass communities provide habitat and food for a variety of marine mammals, any negative effects of *S. muticum* on these communities will have far-reaching effects on the rest of the ecosystem. For example, *S. muticum* also has negative effects on the native sea urchin *Strongylocentrotus droebachiensis* by reducing the abundances of the native kelp species on which it prefers to feed (Britton-Simmons 2004).

Sargassum muticum also attracts diverse epibionts. So, while other canopy-forming species may be affected, it appears that there is a rich epiphytic community associated with stands of this organism. This epibiont-covered canopy provides shelter and food for other floral and faunal species, including juvenile fish (Trowbridge XXXX). Herbivorous species can account for 58-98% of the characterized epifauna (e.g., gastropods, amphipods, cumaceans, pyconogodans, chironomids, polychaetes, echinoderms, and fishes; Viejo 1999).

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = RU

Any social impacts will most likely result from nuisances posed to the commercial and recreational fishing industry. In addition, there is the potential for many negative impacts of the food web ecology of Long Island Sound via direct and indirect interactions with native flora and fauna.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

V. SPECIFIC MANAGEMENT QUESTIONS:

- If the organism successfully invades CT, are there any potential biocontrol mechanisms, i.e. marine herbivores that would likely restrict its distribution?
- Given the evidence that it may have negative effects on local kelp, eelgrass, and turf-forming algae populations, are there any effective means of removal of *S. muticum*? If not, is there a possibility that it will play the same functional role as some of these native species?

VI. RECOMMENDATIONS:

- Secure funds for long-term monitoring programs that will lead to the early detection of established *S. muticum* plants.
- Assess potential vectors in order to minimize the likelihood of the introduction of *S. muticum*.

- Implement public education and technical assistance for aquarium traders, aquaculture specialists, and consumers so that scientists, commercial fishers, and the general public alike can identify and report introductions accordingly.

VII. MAJOR REFERENCES:

Britton-Simmons, K.H. (2004) Direct and indirect effects of the introduced alga *Sargassum muticum* on benthic, subtidal communities of Wasington State, USA. Marine Ecology Progress Series. **277**: 61-78.

Den Hartog, C. (1997) Is *Sargassum muticum* a threat to eelgrass beds? Aquatic Botany. **58**: 37-41.

Global Invasive Species Database (2005). http://www.issg.org/database/species/ecology for *Sargassum muticum*.

Joint Nature Conservation Committee. (1997) Non-native marine species in British waters: a review and directory. (eds.) Eno, N.C., R.A. Clark, W.G. Sanderson. Peterborough: JNCC. 133 pp.

Murray, S.N., L. Fernandez, J.A. Zertuche-Gonzalez. (2004) Status, Environmental Threats, and Policy Considerations for Invasive Seaweeds for the Pacific Coast of North America. Report prepared for the Commission on Environmental Cooperation.

Staehr et al. (2000) Invasion of *Sargassum muticum* in Limfjorden (Denmark) and its possible impact on the indigenous macroalgal community.

Trowbridge, C. (XXXX) A global proliferation of non-native marine and brackish macroalgae.

Viejo, R.M. (1999) Mobile epifauna inhabiting the invasive *Sargassum muticum* and the two local seaweeds in northern Spain. Aquatic Botany. **64**: 131-149.

7. Risk Assessment for the Veined Rapa Whelk *Rapana venosa*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM	*Rapana venosa*	**FILE NO.**	7
ANALYST	Kari Heinonen	**DATE**	01/27/2006
PATHWAY	ballast water, oyster aquaculture, fisheries enhancement		
ORIGIN	Sea of Japan, Yellow Sea, Bohai Sea, and East China Sea to Taiwan		

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

Life Cycle/Life History: *Rapana venosa* is a large, predatory muricid gastropod, with a deep orange columella and aperture. The whelk is dioecious (separate sexes; ICES 2004). Its life cycle consists of 4 main stages, i.e. adult, egg capsule, larva, and juvenile. *Rapana venosa* lays mats of 50-500 egg cases per mat, with each case containing 200-1000 eggs (GISD 2005). The incubation period for the eggs usually lasts 14-21 days depending upon temperature and salinity. While the veliger larvae display considerable variation from hatching time to settelement, they are morphologically competent to settle after 21 days at local temperatures and salinities (with reference to the Chesapeake Bay; as reviewed by GISD 2005). Veligers grow quickly on mixed algal diets consisting of flagellates and diatoms, and local epifaunal species have been demonstrated to stimulate settlement (Mann and Harding 2000). The average life span of the Rapa whelk is 10 years, but individuals may live more than 15 years (Harding and Mann 2003).

Distribution: *Rapana venosa* is native to the Sea of Japan, the Yellow Sea, the Bohai Sea, the East China Sea to Taiwan in the south, and Peter the Great Bay off Vladivostok in the north (Mann and Harding 2003). *Rapana venosa* was introduced into the Black Sea in the 1940s and within a decade spread along the Caucasian and Crimean coasts and to the Sea of Azov. Its range extended into the northwest Black Sea to the coastlines of Romania, Bulgaria and Turkey from 1959 to 1972. Subsequent introductions have been reported in the northern Adriatic and Aegean seas (Mann and Harding 2000). Recent transoceanic invasions by *R. venosa*, have resulted in occurrence of the species in the Chesapeake Bay on the Mid-Atlantic coast of the United States (Harding and Mann 1999; Mann and Harding 2000), on the Brittany coast of France and in the Rio del Plata between Uruguay and Argentina (in Mann and Harding, 2003).

Natural History: Rapa whelks live in oceanic and estuarine water >15 ppt, with temperatures ranging from 4-30ºC. While young rapa whelks need hard substrate, adult whelks spend most of their time burrowed in the soft sediment bottoms of sandy or muddy habitats (Harding and Mann 2003). Both field collections and laboratory observations confirm that adult stages of the species favors sandy bottoms in the coastal, estuary and marine systems. These animals are avid burrowers and spent >95% of the time in the laboratory completely burrowed. Rapa whelks are capable of both feeding and mating while burrowed.

The whelk is a generalist carnivore whose principal prey items include many commercially important bivalve species. In laboratory feeding studies, Chesapeake Bay *R. venosa* prefer hard clams to oysters (*Crassostrea virginica*), soft clams (*Mya arenia*), or local mussels (*Mytilus edulis*), although they will eat these other bivalves when the hard clam is not available. *Rapana venosa* is classified as a gastropod that drills its prey and uses paralytic toxins during feeding.

Rapana venosa are prey to octopods in their native regions. On the North American coast of the North Atlantic, crabs and other gastropod species are considered as potential predators of small sized *R. venosa* (i.e. blue crabs, mud crabs, hermit crabs, oyster drills and moon snails), and sea turtles may also be capable of Rapa whelks less than 100mm in size. Egg cases of the Rapa whelk may also attract predators because of their intense yellow color. These include fishes (e.g. Atlantic croaker, white perch, and striped bass, as well as cownose rays), and crabs (e.g. clue crabs, mud crabs, and hermit crabs). (Harding and Mann 1999)

II. PATHWAY INFORMATION (include references):

Ballast water from commercial and/or military ship traffic is the probable source of introduction into the Chesapeake Bay. *Rapana venosa* are usually planktonic for 14-17 days, which falls within the transit time of 10-24 days from the Black Sea to Virginia. The time interval is well within the temporal window for the survival of the planktonic larvae of *R. venosa*. The area of the Chesapeake Bay is a major center for container, coal transport, and military ship activity (Harding and Mann 1999).

III. RATING ELEMENTS: Rate statements as low, medium, or high.

Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

The suspected vector for transport of larval stages from the eastern Mediterranean or Black Sea is the suspected vector of introduction into the North American Atlantic coast (Mann and Harding 2000). The species has also been associated with the transport of oysters for culture and fishery enhancement in the Orient (Mann and Harding 2000). Egg masses may also be transported in association with marine farming (USGS-NAS undated). Therefore, international trade in live seafood for direct consumption should also be considered.

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Rapana venosa demonstrate large annual temperature tolerances, i.e. 4-30°C. It also seems to tolerate low salinities, water pollution, and oxygen deficiency. Furthermore, long distance dispersal is facilitated by a planktonic phase lasting from a minimum of 14 days to a maximum of 80 days (GISD 2005). This time interval is well within the normal transit time to parts of the East Coast of the United States from the Baltic, Black, Adriatic, or Aegean Seas (Harding and Mann 1999).

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Rapana venosa larvae have been successfully cultured on mixed diets of algal species, and post-settlement juveniles have been cultured on various diets of epifaunal species and local molluscs (Mann and Harding 2000). Because fouling communities on artifical substrates form a rich food resource for juvenile *R. venosa*, and these substrates are common along the East coast of the US, it is highly likely that the species could successfully colonize and maintain populations. The only natural threat to *R. venosa* is the native parasite, the boring polychaete, *Polydora websteri*, which attack juveniles prior to their transition to infaunal lifestyles, and several species of fishes and crabs that may consume smaller whelks. Because of their large maximum size, there are few natural predators that can eat them (Harding and Mann 2003).

Additionally, the volume of ballast arriving in the Chesapeake Bay annually from ports with active Rapa whelk populations increases the chances for obtaining sufficient numbers needed to eventually establish a breeding population (as reviewed in Harding and Mann 1999).

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Potential distribution limits of adult *R. venosa* might be inferred using comparable salinity and temperature data between the recipient and donor regions. Surface circulation, combined with the duration of the pelagic larval phase, suggest that extant adult populations can support recruitment to projected benthic populations if larvae can locate and successfully metamorphose on suitable substrates. Typical summer temperatures from the Chesapeake Bay to New York are capable of supporting larval development. Common zoogeographic boundaries of temperate mollusk species suugest a northern limit of Cape Cod, MA and a southern limit of Charleston, South Carolina (comparable to Hong Kong). In addition, the local collection of egg cases which produce viable pelagic larvae. Its demonstrated ability as a predator on local species, and rapid rate of growth to refuge size all suggest continuing expansion of the current invasion. (Mann and Harding 2000).

CONSEQUENCE OF ESTABLISHMENT

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

The main economic impacts one could expect if the Rapa whelk becomes established in Long Island Sound, CT are those associated with commercially important shellfish. *R. venosa* is an active predator of epifaunal bivalves, and its proliferation is a serious limitation to natural and cultivated populations of oysters and mussels." Harding (2003) states that, "*R. venosa* are credited with drastic declines in Black Sea bivalve populations (including almost complete extinction of the Gudaut oyster bank" (as reviewed by GISD 2005). Also, there is a fishery for the Rapa whelk in the Black Sea, which if developed here, could counter some of the economic losses potentially brought on by the invasion. If a fishery for the Rapa whelk developed, it would remove individuals and their potential offspring from the population, reducing direct and indirect effects on native habitat and fauna.

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = RC

The estimated environmental impact goes hand-in-hand with the economic impact. Since the Rapa whelk is generalist predator of subtidal molluscs, one might expect populations of this type to decline with an invasion by the Rapa whelk. Additionally, Rapa whelks seem to share habitat preferences with their favored food item, the hard clam. The absence of a predation signature on large hard clams consumed by Rapa whelks might be problematic. (Harding and Mann 1999). Overall, a shift in the composition of subtidal molluscan communities should be considered if *R. venosa* invades CT waters or nearby waters.

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = C

Impact from social and/or political influences might be positive for both commercial fishermen and scientists. For example, the Virginia Institute of Marine Science developed a bounty program for *R. venosa.* The legislation passing the bounty program was effective as both a control strategy and a mapping strategy for scientists. The bounty removes the Rapa whelk from the population, thereby eliminating any direct effects of the individual and indirect effects from potential offspring (Harding and Mann 2003)
In contrast, there may be negative impacts on the popular market of clams in LIS. Again, food web interactions between the Rapa whelk and the clam may result in the decline of bivalves, in particular, the hard clam.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

V. SPECIFIC MANAGEMENT QUESTIONS:

- What is the frequency of shipping traffic, whether commercial or military, that Connecticut or surrounding waters receives from both the native range of *Rapana venosa*, and the Chesapeake?
- If the Rapa whelk becomes established in Connecticut waters, how feasible is the establishment of a bounty program?
- Currently, are there any monitoring programs set up and/or communication with neighboring state coastlines so that an invasion will be recognized?
- How open is the general public to the possibility of a Rapa whelk fishery?

VI. RECOMMENDATIONS:

- Decreasing the amount of shipping traffic and regulating the release of ballast water will likely decrease the opportunity for release of the Rapa whelk into Connecticut waterways.
- It is also recommended that development of a bounty program, including scientists, manager, and stakeholders, be investigated.
- Perhaps most important is monitoring for established populations of *R. venosa* in Connecticut waterways.
- Develop a market for the whelk, as previously seen in the Black Sea.

VII. MAJOR REFERENCES:

Global Invasive Species DataBase. Rapana venosa. Accessed 2005. http://www.issg.org/database/species/ecology.asp?si=691&fr=1&sts=sss

Harding, J.M. and R. Mann. 1999. Observations on the Biology of the Veined Rapa Whelk, Rapana venosa (Valienciennes, 1846) in the Chesapeake Bay. Journal of Shellfish Research. 18: 9-17.

Harding, J.M., Mann, R., and V.P. Clark. 2003. Veined Rapa Whelks: Aliens in the Chesapeake. [CD ROM]. Virginia Institute of Marine Science Educational Series Publication No. 56/Virginia Sea Grant Publication No. VSG-03-14. Virginia Institute of Marine Science, Gloucester Point, VA 23062.

ICES. 2004. Alien Species Alert: *Rapana venosa* (veined whelk). Edited by Roger Mann, Anna Occhipinti, and Juliana M. Harding. ICES Cooperative Research Report No. 264. 14 pp.

Mann, R. and J.M. Harding. 2000. Invasion of the North American Atlantic coast by a large predatory Asian mollusc. Biological Invasions. 2: 7-22.

Mann, R. and J.M. Harding. 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.

USGS-NAS, UNDATED Veined Rapa Whelk, Asian Rapa Whelk, *Rapana venosa.*

8. Risk Assessment for the Lionfish *Pterois volitans*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM	*Pterois volitans*	**FILE NO.**	8
ANALYST	Kari Heinonen	**DATE**	02/01/2006
PATHWAY	aquarium trade, currents	**ORIGIN**	Indo-Pacific

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

Life Cycle/Life History: The maximum size record for this species varies according to the source and can be confidently estimated to be between 300 - 380mm TL (11.8 - 15 inches). Red lionfish are external fertilizers that produce a pelagic egg mass following a courtship and mating process that is not well documented. The larvae of red lionfish, like those of many reef fishes, are planktonic. Data recorded for the closely related *Pterois miles* provide the best estimate of red lionfish early development. *P. miles* larvae settle out of the water column after a period of approximately 25 to 40 days, at a size of 10-12 mm in length, and become sexually mature at 180-190mm and 140-160 g body mass.

Distribution: The native distribution of *Pterois volitans* is in appropriate reef habitats in the Indo-Pacific, ecompassing a large area from Western Australia to the French Polynesia on an East-West transect, and Northern Japan, Southern Korea, and Lord Howe Island on a North-South transect. *Pterois miles*is found in the Red Sea and Sumatra. More recently, a number of lionfish have been caught off the East Coast of the United States from Florida to New York, including juveniles caught in lobster pots in the eastern end of Long Island Sound (Robins

2005). Lionfish are most commonly seen off the soueastern US, but 11 juvenile lionfish were captured alive off Long Island, NY from September 2001 to October 2003 at depths of 0-5m (Meister et al. 2005). While collections occur in fairly shallow water, Meister et al. (2005) report occurrence in much deeper waters (40-99m). It has also been proposed that the mean critical thermal minimum is 10°C and concluded that lionfish could overwinter on the continental shelf of the southeastern US, resulting in a northern limit of Cape Hatteras (Kimball et al. 2004, Mesiter et al. 2005).

Natural History: Lionfishes are often inhabitants of near and offshore coral and rocky reefs to depths of 50 meters. The species shows a clear preference for sheltering under ledges, caves, and crevices during daylight hours. It is also known to occur in bays, estuaries, and harbors (Robins 2005), as well as lagoons (Meister et al. 2005). Most observations of the southeastern coast of the United States place the fish in live-bottom reefs (Meister et al. 2005).

The red lionfish is a solitary predator of small fishes, shrimps and crabs. Prey are stalked and cornered or made to feel so by the outstretched and expanded pectoral fins of the red lionfish in full ambush mode. Prey are ultimately obtained with a lightning-quick snap of the jaws and swallowed whole. Cannibalism has been observed for this species in the wild (Robins 2005). Investigation of gut contents of a specimen captured off of South Carolina revealed one unidentifiable fish species and one anthiine serranid (Meister et al. 2005).

Given the tendency of the red lionfish to retreat to areas of hiding by day, this species is thought to be mostly nocturnal. However, red lionfish have been observed to feed during the day and studies of captive specimens imply that *Pterois* that have taken up refugia may simply be those individuals that have recently fed and are sated.

Published records of natural predators of adult red lionfish are unknown. But again, studies of *Pterois miles* may provide us with some indication of the natural history of *P. volitans*. In the Gulf of Aqaba, Red Sea, the piscivorous cornetfish, *Fistularia commersoni*, may be a predator of *Pterois miles* (Bernadsky and Goulet 1991). Judging by the presence of a specimen of *P. miles* in the stomach of a large *F. commersoni*, and its particular orientation therein, a published note concludes that cornetfish in the Red Sea may utilize their ambush tactics to seize lionfish safely from the rear, consuming them tail first. As cornetfishes are widespread, effective piscivores, species sympatric with *P. volitans* may be predators of the same. Other predators of the red lionfish might include sharks, as many sharks are known to consume noxious or venomous organisms with no obvious ill effects. (Robins 2005)

III. PATHWAY INFORMATION (include references):

Published reports of this species in waters of the East Coast of the United States date to a number of individuals first observed off the coast of North Carolina in August, 2000. Since that time, numerous observations of red lionfish have been recorded from South Florida to Long Island, NY. The fact that ballast water of large ocean going vessels is a documented means of dispersal for non-native marine and estuarine organisms, including fishes, and that the planktonic nature of larval red lionfish or the fact that the species is purported to occur in some harbors, give rise to speculation that it is not unreasonable that the species has gained a foothold on the U.S. east coast via ballast water transport. However, it is more likely that the species may owe its presence in U.S. waters to the deliberate release of captive specimens. Numerous fishes (mostly freshwater species) have been introduced to areas beyond their native range in this fashion. (Robins 2005) In fact, Meister et al. (2005) cite the release of the lionfish off Florida during a hurricane as the first time an aquarium release has been documented as the 'likely source of a successful establishment'.

III. RATING ELEMENTS: Rate statements as low, medium, or high.
Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = RC

Because lionfish were released from captivity and are a popular aquarium fish, it is very likely that the species are in the pathway. Visiting lionfish from southeastern US waters are fair evidence that currents also act as a significant pathway. Because lionfish lay an egg mass that is pelagic and larval transport pathways have been described from the southeastern shelf to the northeastern shelf and Bermuda, it is likely that spawning along the southeastern continental shelf supplied juvenile lionfish to Long Island Sound. Larval duration of lionfish range from 25 to 40 days and is well within the range of transport times of other shelf species carried to coastal regions of the northeastern shelf (Whitfield et al. 2002).

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = RC

Successful establishment of the species after aquarium release off the coast of Florida is evidence that the organism survives release from captivity. However, surviving transport via northward currents is most likely dependent upon temperature, and therefore season. To date, no lionfish species have been collected north of Cape Hatteras in the autumn, winter and spring- indicating that the lionfish might not survive in transit in colder temperatures.

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = VC

Lionfish are able to cope with energy demands and the lowering of ambient temperature by changing their physiology and behavior, and lowering metabolism. They can also withstand varying durations of starvation (Fishelson 1997). However, temperature fluctuations in Long Island Sound will most likely adversely affect the success of the lionfish, as temperatures decline to 5°C during winter months, which is less than the lower lethal limit for the species. It is likely that lionfish perish or return to warmer waters when water temperatures decline off northeastern US (Whitfield et al. 2002). In addition, competition for prey should not adversely affect the lionfish (Meister et al. 2005). Lionfish are top, opportunistic predators of coral reefs and exhibit the ability to adapt quickly in terms of foraging techniques and predator avoidance. These traits only increase their chances of success in Long Island Sound. Multiple size groups of lionfish have also been observed, which strongly supports the suggestion that lionfish are reproducing in invaded habitats (Mesiter et al. 2005). Polluted areas (as in some reef systems) are expected to negatively impact lionfish populations (Fishelson 1997). Therefore, areas with poor water quality would probably not support lionfish colonization. Finally, the lionfish has few natural predators in its native environment, and potential predators along the eastern shelf of the US have no experience with venomous spines of lionfish (as reviewed in Whitfield et al. 2002). Lack of natural predators and few potential predators only increase this organisms chance for survival.

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = RC

Because lionfish lay an egg mass that is pelagic and larval transport pathways have been described from the southeastern shelf to the northeastern shelf and Bermuda, it is likely that spawning along the southeastern continental shelf supplied juvenile lionfish to Long Island Sound. Larval duration of lionfish range from 25 to 40 days and is well within the range of transport times of other shelf species carried to coastal regions of the northeastern shelf (Whitfield et al. 2002). While the organism has spread beyond the colonized area, it is not likely that it will persist across seasons as the cold temperatures cause the species to perish or retreat to warmer waters.

CONSEQUENCE OF ESTABLISHMENT

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = L
Uncertainty Code (VC-VU) = RC

Although the red lionfish is valued as a food fish in many parts of its native range, its value as an aquarium animal or as a source of attraction to divers far exceeds its economic value as table fare. The red lionfish is a staple of the trade in aquarium fishes, an industry whose value worldwide is estimated to exceed a billion dollars. Similarly, recreational divers of areas where the red lionfish is found count the species among the many attractions of diving a tropical coral reef.

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = VU

Impacts of the lionfish on food web dynamics of Long Island Sound, CT is unknown. However, food consumption experiments on 80 adult lionfish off the coast of Israel show that they could potentially consume over 50,000 small-bodied fish a year (Fishelson 1997, as reviewed by Meister et al. 2005). If lionfish populations increase in Long Island Sound, this could have detrimental impacts on juvenile and small-bodied fishes inhabiting the same waters as the invasive lionfish. Given the fact that little is known about its environmental impacts, it is difficult to say what it would be if the lionfish became established. More studies are needed.

Estimate impact from social and/or political influences. (Supporting Data with

reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = C

Since lionfish are responsible for invenomation of humans (Aldred et al. 1996), fishing/ recreational regulations may be necessary to protect the public from health risks. Restricting fishing/diving to specific areas could result in a decrease in profit from these activities and directly related activities (craft rental, bait supply, etc.). A result of which may be an increase in taxes to append losses associated with lionfish invasion.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = M/L

V. SPECIFIC MANAGEMENT QUESTIONS:

- In light of the lack of reproductive and food web information available on the lionfish, it is important to develop an empirical understanding before any management questions are asked. However,
- What are potential predators of lionfish in LIS? What do their gut contents show? Is the pattern seasonal?
- What are potential prey items of the lionfish in LIS? Do gut content studies support this?
- What is the reproductive status of the lionfish found in LIS? Are they breeding here? Are they visiting here? What are the results of quantitative surveys?

VI. RECOMMENDATIONS:

- Increased sampling efforts, including wintertime in situ observations, including temperature data and habitat type.
- Food-choice experiments, gut content analysis of P. volitans in LIS to determine diet in invaded range.
- Studies investigating reproductive state to assess impacts on reef communities.

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VII. MAJOR REFERENCES:

Aldred, B., T. Erickson, J. Lipscomb. 1996. Lionfish envenomations in an urban wilderness. Wilderness and Environmental Medicine. 7: 291-296.

Bernadsky, G. and D. Goulet. 1991. A natural predator of the lionfish, Pterois miles. Copeia. 1: 230-231.

Fishelson, L. 1997. Experiments and observations on food consumption, growth and starvation in *Dendrochirus brachypterus* and *Pterois volitans* (Pteroinae, Scorpaenidae). Environmental Biology of Fishes. 50: 391-403.

Kimball, M.E., J.M. Miller, P.E. Whitfield, J.A. Hare. 2004. Thermal tolerance and potential distribution of invasive lionfish (Pterois volitans/miles complex) on the east coast of the United States. Marine Ecology Progress Series. 283: 269-278.

Robins, R.H. 2005. Biological Profile: Red Lionfish. Ichthyology at the Florida Museum of Natural History. Web accessed: 01/06/2005. http://www.flmnh.ufl.edu/fish/Gallery/Descript/RedLionfish/RLionfish.html.

Meister, H.S., D.M. Wyanski, J.K.Loefer, S.W. Ross, A.M. Quattrini, K.J. Sulak. 2005. Further evidence for the invasion and establishment of Pterois volitans (Teleostei; Scorpaenidae) along the Atlantic Coast of the United States. Southeastern Naturalist. 4: 193-206.

Whitfield, P.E., T. Gardner, S.P. Vives, M.R. Gilligan, W.R. Courtenay, G.C. Ray, J.A. Hare. 2002. Biological invasion of the indo-pacific lionfish Pterois volitans along the Atlantic coast of North America. Marine Ecology Progress Series. 235: 289-297.

9. Risk Assessment for the pleated sea squirt *Styela plicata*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM	*Styela plicata*	**FILE NO.**	9
ANALYST	Kari Heinonen	**DATE**	03/16/2006
PATHWAY	hull fouling, aquaculture	**ORIGIN**	US to West Indies

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

LIFE CYCLE/LIFE HISTORY: The reproduction of *Styela plicata* is similar to that of its congener *S. clava*. The tunicate is hermaphroditic, but its male and female gonads mature at different times so it is not self fertile. It reproduces sexually and is oviparous. Fertilzation is external and larval development is from 0-24 hours. Larvae are in planktonic phase for approximately one to three days prior to settlement and metamorphosis into the sessile adult. The species can live for 2-3 years and reaches sexual maturity at approximately 10 months. (ISSG 2006) The species attains an average maximum size of approximately 3.5 inches (Fuller 2005). However, S. plicata is only believed to be able to spawn in waters above 15˚C (ISSG 2006). Additionally, fertilized eggs do not develop at lower salinities, i.e. 22 to 26 ppt (Thiyagarajan and Qian 2003).

DISTRIBUTION: The native range of *Styela plicata* includes North Carolina and Florida to the West Indies, and is abundant in the northern Gulf (as reviewed by Fuller 2005). The species is commonly found in warm and temperate regions (as reviewed by Thiyagarajan and Qian 2003).

NATURAL HISTORY: Also known as the pleated sea squirt or leathery tunicate. The species can be identified by its oval shape, and its grayish/tannish tunic with red or purple stripes around the siphons. (Fuller 2005) It is very similar to its congener *Styela clava*. It is a solitary tunicate that often occurs in large clumps of many unattached individuals (as reviewed in Fuller 2005).
Styela plicata individuals that do grow attached to substrate are more numerous and have greater percent cover in shaded areas and those far from the seafloor (Glasby 1999). Its

habitat is very similar to its congener S. clava, i.e. it occurs in coastlands, inlets, and marine habitats. It is common on rocks, pilings, and can reach densities of 500-1500 individualsper square meter up to 25m depth. Like its congener, S. plicata is capable of withstanding temperature and salinity fluctuations.

IV. PATHWAY INFORMATION (include references):

Ballast water or ship fouling (Fuller 2005). Other possible methods include shipment with oysters.

III. RATING ELEMENTS: Rate statements as low, medium, or high.

Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = RU

While larvae would not survive in ballast water, adults fouling the hulls of ships will likely produce larvae in ports. This makes the probability of the organism being in the pathway to Long Island Sound very high if and when ships from the native range of the tunicate enter ports.

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = RU

While larvae are short-lived, adult *Styela* are considered a very hearty species and would probably survive in transit, given temperatures and salinities in their favor.

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Styela plicata could easily colonize and maintain a population where introduced, especially if suitable habitat exists in the invaded area. The tunicate often settles on hard substrates, i.e shells of dead oysters and scallops on the muddy seafloor (Cohen et al. 2000). Since this habitat is abundant in many shallow areas of Long Island Sound, it is highly likely that S. plicata will establish breeding populations if it is introduced to the region. This species also

has rapid rates of growth and reproduction, so it can colonize substrata quickly and densely (Morris et al. 1980).
Additionally, the organism doesn't have many natural predators, possibly due to the chemical defense of secondary metabolites in the gonadal tissue (Pisut and Pawlik 2002).

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Styela plicata grows quickly and densely. Currents could transport larvae over short distances, which could enable it to spread slowly into other regions. Because it fouls hulls, humans would probably aid in its establishment in nearby waterways.

CONSEQUENCE OF ESTABLISHMENT

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Styela plicata is a dominant species that fouls mariculture cages, resulting in high mortality rates of oysters (Zheng and Huang 1990). Aquaculture / mariculture facilities in Long Island Sound could be greatly affected by such biofouling. With its ability to reach great densities, *Styela plicata* could have negative impacts of native and aquaculture species not just via smothering, but also through competition for space and food, as well as predation of larvae from the water column (Global Invasive Species Database 2005)

Styela plicata is also used in biomedical research because it possesses high amounts of heparin, a protein involved in the coagulation of blood (Cavalcante et al. 2000). This is analogous to blood clotting in vertebrates, which makes S. plicata an ideal model for biomedical studies.

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = C

In San Diego, California, one of the main impacts of introduction has been replacement of the native solitary tunicates *Pyura haustor* and *Ascidia ceratodes* (Fuller 2005). Bingham and Walters (1989) found that S. plicata consumes a variety of invertebrate larvae, but that an aggregation of solitary tunicates does not significantly deplete the local supplies of larvae. The lack of small scale depletion effects is probably due to the fact that temporal and spatial patchiness of in larval supply combined with selective feeding by the ascidians and escape responses of larvae. Regardless, depletion of invertebrate larvae could have cascading effects on primary productivity or future invertebrate community structure.

Styela plicata may also provide small scale structural complexity for the settlement of other fouling organisms, i.e. the arborescent bryozoan *Bugula neritina* frequently settles on the tunic of *S. plicata* (Walters 1992). While this might might help to increase the number of species in an area, *S. plicata* has also been shown to exclude the encrusting bryozoan *Schizoporella (*Sutherland 1978) during competition for space.

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = VC

Impact from social or political imfluences might include rapid removal, as growth of *S. plicata* on mariculture cages will adversely affect the economic output of the facility. For example, dense fouling on fishing gear, moorings, and ropes can be time-consuming to remove and can cause entanglements. Hull fouling increases drag on boats, resulting in an increase in fuel costs.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

V. SPECIFIC MANAGEMENT QUESTIONS:

- What species of invertebrate larvae and phytoplankton do/would Styela plicata exploit if it invaded Long Island Sound?
- How would this affect trophic interations involving these food species?
- Will the organism overwinter, i.e. freezing has been known to kill a large portion of populations elsewhere?
- Are there effective means for rapid response removal in the event that they start to fould mariculture cages?

VI. RECOMMENDATIONS:

- Monitoring. This species is very similar to its congener S. clava which is already established in Long Island Sound?
- Continue studies to determine if there are any natural predators at any life stage, what native species it competes with, and what native species it consumes.

VII. MAJOR REFERENCES:

Cavalcante, M.C.M., S. Allodis, A.P. Valente, A.H. Srtaus, H.K. Takahashi, P.A.S. Mourao, and M.S.G. Pavao. 2000. Occurrence of Heparin in the Invertebrate Styela plicata (Tunicata) is Restricted to Cell Layers Facing the Outside environment. The Journal of Biological Chemistry. **275**: 36189-36196.

Cohen,B.F. , D.R. Currie, and M.A. MacArthur. 2000. Marine and Freshwater Research. **51**: 689-702.

Fuller, P. 2005. Styela plicata. USGS Non-indigenous aquatic species database, Gainseville, Florida.

Glasby, T.M. 1999. Journal of Experimental Marine Biology and Ecology. 234: 275-290.

Morris, R.H., D.P. Abbott, and E.C. Haderlie. 1980. Intertidal Invertebrates of California. California: Stanford University Press.

Pisut, D.P. and J.R. Pawlik. 2002. Anit-predatory chemical defenses of ascidians: secondary metabolites or inorganic acids? Journal of Experimental Marine Biology and Ecology. 270: 203-214.

Sutherland, J.P. 1978. Functional roles of Schizoporella and Styela in the fouling community at Beaufort, North Carolina. Ecology. 59: 257-264.

10. Risk Assessment for the grapsid crab *Hemigrapsus penicillatus*

ORGANISM RISK ASSESSMENT FORM (With Uncertainty and Reference Codes)

ORGANISM	*Hemigrapsus penicillatus*	**FILE NO.**	10
ANALYST	Kari Heinonen	**DATE**	05/07/2006
PATHWAY	hull fouling, ballast water	**ORIGIN**	Japan

I. LITERATURE REVIEW AND BACKGROUND INFORMATION (Summary of life cycle, distribution, and natural history):

LIFE CYCLE/LIFE HISTORY: Very few sources of primary literature regarding the life history of *Hemigrapsus penicillatus*) are available. In that literature, it does say that the species has planktonic larvae (like most marine crabs) and it is available to reproduce when very young (Noël, et al. 1997). *Hemigrapsus penicillatus* matures when the female reaches 6 to 7 mm carapace width and produces 5 to 6 broods during a breeding season. The peak of the breeding season is during summer, at which time the ovarian activity is also apparently accelerated. The major environmental factor which controls the breeding in these crabs appears to be temperature. *H. penicillatus* is submerged at every high tide, and is relatively inactive from late November to February when the ambient water and air temperatures are rather low. The length of the breeding season of these crabs appears to be inversely proportional to the period of their winter dormancy (Pillay and Ono 1978). Because the crab is a congener to another invader *Hemigrapsus sanguineus*, it is expected to have a similar life cycle/life history. In the Bay of Biscay, France where *H. penicillatus* has invaded, it's spawning period begins in May (Noël, et al. 1997), similar to when *H. sanguineus* typically has its first brood in the NW Atlantic.

DISTRIBUTION: In its native range the crab inhabits cold temperate to subtropical parts of Northwest Pacific Ocean. It is one of the most common shore crabs in Japan. *Hemigrapsus penicillatus* has also invaded France and extended its range from Laredo, Spain to Fromentine, France (700 km away; Noel et al. 1997). There is also a Dutch population that has expanded its range to Belgium (Asanaka and Watanabe 2005).

NATURAL HISTORY: It should be noted that the *Hemigrapsus penicillatus* invasions may actually have been misidentified. What we think are *Hemigrapsus penicillatus* may actually be *Hemigrapsus takanoi* (Asanaka and Watanabe 2005). The crab is known as an intertidal species commonly found below stones or oysters in estuaries, lagoons, harbors, and sheltered bays (Asanaka and Watanabe 2005), but has been recorded at depths up to 20m in some areas. It is often found on muddy shores between high and low tide marks (Noel et al. 1997).

The crab is extremely similar in appearance to *Hemigrapsus sanguineus*. The only difference is a short tuft of hairs at the joint of the cheliped dactylus in males instead of the bulb that is characteristic of *H. sanguineus* males. The average size of H. penicillatus is approximately 20mm carapace width (Noel et al. 1997, Asakura and Watanabe 2005).

The only documented predators of this crab are herons and sea-gulls (Noel et al. 1997), as well as larger conspecifics (Okamoto and Kurihara 1989). The crab is known to consume the alga *Enteromorpha prolifera*, sessile matter (i.e. detritus and diatoms), as well as small conspecifics (Okamato and Kurihara 1989).

V. PATHWAY INFORMATION (include references):

In other regions where the crab has invaded, the pathway is unknown. It has been suggested that the crab could have been introduced with Asian oysters, or by shipping lines (via ballast water or in fouling assemblages on hulls) to France(Noel et al. 1997). Its congener *H. sanguineus* is thought to have invaded the Northeast coast of North America by similar means. That said, it is not unlikely that *H. penicillatus* could invade North America.

III. RATING ELEMENTS: Rate statements as low, medium, or high.

Place specific biological information in descending order of risk with reference(s) under each element that relates to your estimation of probability or impact. Use the reference codes at the end of the biological statement where appropriate and the Uncertainty Codes after each element rating.

PROBABILITY OF ESTABLISHMENT

Estimate probability of the nonindigenous organism being on, with, or in the pathway. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Since its true pathway is unknown, we look to all possible vectors. These are ballast water, hull fouling, and shipping with Asian oysters. Since New Haven, CT and areas close to NY have large Asian populations, it might be considered that oysters shipped to Asian markets could have *H. penicillatus* as hitch hikers. It is also not ruled out that *H. penicillatus* will cross the Atlantic to the American side with water ballast (Asakura and Watanabe 2005).

Estimate probability of the organism surviving in transit. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Adults might survive if transported in fouling assemblages on hulls of ocean-going vessels. *Hemigrapsus pencillatus* has been observed nestled in fouling communities attached to the hulls of vessels traveling long distances (Gollasch 1999). *Hemigrapsus penicillatus* also tolerates a wide range of temperatures (i.e. cold to tropical waters; Noel et al. 1997), and would probably survive transport in ballast water.

Estimate probability of the organism successfully colonizing and maintaining a population where introduced. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

In other areas where the crab has been introduced, it has successfully colonized and maintained populations, i.e. France, Spain, Netherlands. This is in part due to the fact that there are similarities between native and invaded regions, like temperature ranges, habitat, prey type, predator type, etc. Connecticut would provide many similar resources to those necessary for its colonization and maintenance. These include, but are not limited to: rocky, muddy, and sandy habitats; estuaries and other sheltered places; algal and faunal prey,etc. One might also want to look to *Hemigrapsus sanguineus* as a model. It invaded nearly 20 years ago, became established, and spread both North and South of New Jersey. On the other hand, there is high niche overlap between *H. sanguineus* and *H. penicillatus*, which could result in intense competition and hinder the colonization of *H. penicillatus* if introduced.

Estimate probability of the organism to spread beyond the colonized area. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

This alien species is likely to extend its range to a large part of European coasts where it has invaded sheltered habitats. A population has established in the harbour of Le Havre in Normandy and another in the Netherlands. In fact, the distribution of this species in Europed has increased at an estimated rate of over 100km per year (Noel et al. 1997). *H. sanguineus* has colonized a large part of the Atlantic coast of the USA (Asakura and Watanabe 2005). Therefore, similar traits between congeners and similarity between European and American coastlines lead one to believe that it is extremely probable for the crab to spread beyond the colonized area if it were to become established in Connecticut.

CONSEQUENCE OF ESTABLISHMENT

Estimate economic impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = M
Uncertainty Code (VC-VU) = RU

There is nothing in the literature that elucidates any anticipated economic impact, unless they occur as an indirect result of altered food webs. While its congener *H. sanguineus* is expected to have direct and indirect impacts on economically important species in LIS, there is no evidence from the literature of predation on important bivalves…though *H. penicillatus* is found in oyster reefs. Not enough is known to define negative impacts, but not enough is know to exclude them

Estimate environmental impact if established. (Supporting Data with reference codes)

Element Rating (L,M,H) = H
Uncertainty Code (VC-VU) = VC

Preliminary observations of *H. penicillatus* in the Bay of Biscane do not suggest that there will be high niche overlap with native marine organisms (Noel et al. 1997). However, its habitat and feeding habits are similar to that of the green shore crab *Carcinus maenas* and *Hemigrapsus sanguineus* along the CT shoreline. This could lead to direct competition for food and shelter resources. In invaded European regions, *H. penicillatus* is especially abundant with 10-20 specimens per square meter and often times occurs at a ratio of 40-80 to every 1 *C. maenas*. A similar situation exists in Long Island Sound, where *H. sanguineus* greatly outnumbers C. maenas. The environmental impacts of the invasion of CT by *H. penicillatus* may be similar to that of *H. sanguineus* (and how it replaced the Green crab). Apparent replacement of one exotic species by another, or an additive effect are potential outcomes.

The crab also serves as a food source for such shore birds as herons and sea-gulls (also present in CT). Therefore, if *H. penicillatus* invades, the crab may serve as a new food source or replace existing food resources for shorebirds in CT. These changes to food web structure could propagate up or cascade down the trophic levels.

Estimate impact from social and/or political influences. (Supporting Data with reference codes)

Element Rating (L,M,H) = L
Uncertainty Code (VC-VU) = VU

At this time, it is difficult to say whether or not there would be any impacts from social or political influences. If the crab had any type of negative impact on an economically important species via altered food web interactions, we would expect to see those repercussions here.

IV. ORGANISM/PATHWAY RISK POTENTIAL (ORP/PRP) = H/H

V. SPECIFIC MANAGEMENT QUESTIONS:

- Are we correctly identifying *Hemigrapsus penicillatus*? Is it *Hemigrapsus takanoi*?
- Could it already be here, and it has been misidentified as its look-alike congener Hemigrapsus sanguineus?
- How are the crabs transported to the U.S.? Is there a way to prevent this (i.e. ballast water monitoring?) to slow the expansion of the crab into uninvaded areas, as well as to prevent the export of the crab to areas where it is not yet established?
- Are monitoring projects set up to identify introductions? Has the public been made aware of the differences between *H. sanguineus* and *H. penicillatus*?

VI. RECOMMENDATIONS:

- Monitor research investigating the impacts on other invaded ecosystems, including native fauna and flora so that examples can be applied to CT marine waters.

- Monitor vessel traffic and ballast water for future introductions.

VII. MAJOR REFERENCES:

Asakura A. and S. Watanabe. 2005. *Hemigrapsus takanoi*, new species, a sibling species of the common Japanese intertidal crab *H. penicillatus* (Decapoda: Brachyura: Grapsoidea). *Journal of Crustacean Biology*, 25: 279-292.

Gollasch S. 1999. The Asian decapod *Hemigrapsus pencillatus (*de Haan) (Grapsidae, Decapoda) introduced in European waters: status quo and future perspective. *Helgoländer Meeresuntersuchungen.* 52: 359-366.

Noël P.Y., E. Tardy, C.D. d'Acoz. 1997. Will the cran Hemigrapsus penicillatus invade the coasts of Europe? *Ecologie*. 320: 741-745.

Okamoto K. and Y. Kurihara. 1989. Feeding habit and food selection of the grapsid crab Hemigrapsus penicillatus. *Japanese Journal of Ecology*. 39: 195-202.

Pillay K.K. and Y. Ono. 1978. The breeding cycles of two species of grapsid crabs (Crustacea:Decapoda) from the North Coast of Kyushu, Japan. *Marine Biology*. 45: 237-248.

Final two analyses to be added after review - *Crassostrea ariakensis, Caulerpa taxifolia*

Conclusions and Discussion

Results of the Generic Nonindigenous Aquatic Organism Risk Analysis Review Process indicated that the risk associated with the introduction of all of the species presented here was High/High, with the exception of the *P. volitans* for which the estimated risk is Medium/Medium. It is important to note that for each individual risk assessment and resultant rating, there are three associated types of uncertainty. These are: (1) uncertainty of the process, (2) uncertainty of the assessor, and (3) uncertainty about the organism. Unfortunately, all three types of uncertainty will exist regardless of future advancements. Our goal was aimed at reducing the uncertainty as much as possible.

To reduce uncertainty of the process, the methodology was conducted in a consistent manner. It is important that this process was never static or routine and therefore we updated our risk methodologies as new information became available and as procedural errors were detected. For example, the Risk Analysis Review Process was first used to assess the risk associated with the introduction of *H. sanguineus* and *Didemnum* sp. A. Both species are currently established in

LIS. While the process was useful for summarizing current knowledge, we discovered that it is better used for species that are yet to be introduced to the Sound. A different process will have to be developed / used to assess the risk associated with already-established species. For example, The Training and Implementation Guide for Pathway Definition, Risk Analysis, and Risk Prioritization (ANSTF and NISC 2007) is a new document that applies to unintentional, man-made pathways and might be useful for preventing the importation of nonnative species or the export of some of the Sound's invasive species to areas that are un-impacted.

The uncertainty of the assessor is best addressed by employing the most qualified persons to conduct the assessments. The quality of the outcome of each assessment does reflect the quality of the assessor. To reduce this type of uncertainty, we distributed drafts of the risk assessments to experts in the field or those individuals working with particular organisms for comments and review. Individuals who could also provide anecdotal evidence were also contacted. Input from these individuals, as well as expert reviewers, was incorporated into each of the risk assessments.

The uncertainty of the organism is probably the most difficult to counter. This should be considered intuitive because the need for information regarding a particular species is what initiated the development of a risk analysis review process (Risk Assessment and Management Committee 1996), but the quality of a risk assessment is directly related to the quality of data available about the organism and the ecosystem that will be invaded. Organisms that have been researched extensively were most easily assessed, and organisms for which little is known were not easily assessed. Therefore, the risk of importing an organism associated with a high degree of biological uncertainty represents a real ecological, economic, and perceived risk. These risks were not, however, based on the high degree of biological uncertainty of a particular organism but rather on the pathway that contains a high concentration of these individuals. Additionally, the high degree of biological uncertainty aided us in the process of identifying research needs and asking management questions, but also identified particular pathways for species of concern.

Most of the information used in conducting these risk assessments was obtained from peer-reviewed journals, but some is anecdotal or based on experience. All of it has been subject to review and updates, thus allowing for an estimation of risk based on the best available sources. This estimation can be used to determine management action like the restriction or prohibition of pathways, but it can also be used to identify future needs for management action.

In our case, almost the estimated risk associated with most organisms was high, i.e. both high probability of establishment and high consequence of establishment. High organism risk potential is defined as an unacceptable risk or rather, an organism of major concern for which mitigation would be justified. For species like *P. volitans* that have a medium probability of establishment and a medium consequence of establishment, there is a medium organism risk potential. Medium organism risk potential is similarly defined as an unacceptable risk, or organisms of moderate concern for which mitigation is also justified.

Because mitigation is justified for all of the organisms presented here, it is suggested that risk management policies be developed as early as possible. The Risk Assessment and Management Committee (RAMC) of the ANS Task Force (1996) outline elements to consider in risk management policy. These are the risk assessments, available mitigation safeguards (i.e. permits, industry standards, prohibition, and inspection), resource limitations (i.e. money, time, locating qualified experts, necessary information), perceived damage (i.e. public perceptions), social and political influences, as well as benefits and costs of the mitigation.

The RAMC also identifies four operational steps that should be accomplished in developing a risk management policy. These are: (1) maintain communication and input from interested parties, (2) maintain open communication between risk managers and risk assessors, (3) match the available mitigation options with the identified risks, and (4) develop an achievable operational approach that balances resource protection and utilization.

In order to maintain communication and input from interested parties, participation should be actively solicited as early as possible. These might include researchers, managers, industrial representatives, non-governmental organizations, EPA representatives, CT DEP, OLISP, educators, etc. By including all parties initially, the revisitation of issues already examined is prevented. Likewise, there should be open communication not just between managers and assessors, but among all interested parties. This is necessary to ensure that all policy will be relevant when completed, but also to ensure that the policy is based on the most recent information. It is also important that interested parties do not attempt to drive or skew the outcome of the assessments as these are supposed to be unbiased by nature.

Matching available mitigation options with the identified risks and developing a realistic approach are probably the most difficult tasks to accomplish. It is sometimes useful to create a mitigation matrix by placing the organism(s) in review along one axis and available mitigation options along the other. The efficacy for control is recorded at the intersection of the organism and mitigation option. This process can help to identify the mitigations needed to reduce the risk to an acceptable level. Once these mitigations are identified, a realistic operational approach can be developed. This approach, however, should be examined in terms of its feasibility, and then, if employed, by monitoring to determine if a maximum balance between protection and available resources has been achieved.

While the estimated risk dictates whether or not mitigation steps are justified, it also allows managers to determine necessary research required for determining probabilities and consequences of establishment in light of the lack of information on a specific organism. A common trend in all of the analyses presented here is that there is a lack of knowledge regarding the impacts of the species of concern on the food web in the recipient region. This is in part due to the fact that most investigations of nonindigenous species in coastal systems have been concerned with the essential task of documenting identities, and a handful of subsequent studies focus on impacts on native flora and fauna (Grisholz et al. 2000).

There is a significant disconnect between the impacts of non-native species on food webs in coastal systems that are found to occur years after the initial invasion, and the number of studies that are conducted to elucidate these impacts. There are two questions that examining food web interactions can help to answer, and each of these are important in completing risk analyses. Can the effects on food webs be forecasted? How good are we at predicting the impacts? Branch and Steffani (2004) examined the consumption of a bivalve by higher trophic levels, and found that they could predict its effects on food webs with some certainty. Predicting or defining these impacts is very important in determining the consequence of invasions, and therefore in assessing risk which ultimately aid in the prevention of aquatic nuisance species. It is suggested that funding be prioritized for determining the impacts of nonindigenous ANS, especially when they are a potential risk and little research has been done regarding their ecological interactions.

References

Bax, N., J. T. Carlton, A. Mathews-Amos, R. L. Haedrich, F. G. Howarth, J. E. Purcell, A. Rieser, A. Gray (2001) The Control of Biological Invasions in the World's Oceans. *Conservation Biology*. **15:** 1234–1246.

Branch, G. M. and C.N. Steffani. 2004. Can we predict the effects of alien species? A case-history of the invasion of South Africa by *Mytilus galloprovincialis* (Lamarck). *Journal of Experimental Marine Biology and Ecology*. **300**: 189-215

Carlton, J.T. 1996. Pattern, process, and prediction in marine invasion ecology. Biological Conservation **78**: 97-106.

Carlton, J.T. 1999. The scale and ecological consequences of biological invasions in the world's oceans, pp. 195-212, in: Odd Terje Sandlund, Peter Johan Schei, and uslaug Viken, editors, *Invasive Species and Biodiversity Management*. Kluwer Academic Publishers, Dordrecht, 431 pp.

Carlton, J.T. and J.B. Gellar. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. Science **261**: 78-82.

Connecticut Aquatic Nuisance Species Management Plan. 2006.

Crooks, J.A. and H.S. Khim. 1999. Architectural vs. biological effects of a habitat-altering, exotic mussel, *Musculista senhousia*. *Journal of Experimental Marine Biology and Ecology.* **240**: 53-75.

Grosholz, E.D., G.M. Ruiz, C.A. Dean, K.A. Shirley, J.L. Maron, P.G. Connors. 2000. The impacts of a nonindigenous marine predator in a California Bay. *Ecology*. **81:** 1206-1224.

Groves, R.H., F. D. Panetta, J. G. Virtue. 2001. Weed Risk Assessment. Australia: Csiro Publishing, 256 Pp.

Hayes K, (1997). A review of ecological risk assessment methodologies. Chrimp technical report **13**.

Kohler, C.C. 1992. Environmental risk management of introduced aquatic organisms in aquaculture**.** *ICES marine science symposia* Copenhagen [ICES MAR. SCI. SYMP.].

Kolar, C.S. and D.M. Lodge. 2001. Progress in invasion biology: predicting invasions. *Trends in Ecology & Evolution*. **16**: 199-204.

Lafferty, K.D. and A.M. Kuris. 1996. Biological Control of Marine Pests. *Ecology*. **77**: 1989-2000.

Lohrer, A.M. 2000. Mechanisms and consequences of an exotic crab species invasion. Doctoral Dissertation, Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, CT USA. 147 pp.

Mack, R.N., D. Simberloff, W. M. Lonsdale, H. Evans, M. Clout, F. A. Bazzaz. 2000. Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control. *Ecological Applications*. **10**: 689-710.

Munawar, M., I.F. Munawar, N.E. Mandrak, M. Fitzpatrick, R. Dermott, J. Leach. 2005. An overview of the impact on the food web integrity of the North American Great Lakes: Lake Erie example. Aquatic Ecosystem Health and Management Society. **8**: 375-395.

National Research Council. 1993. Issues in risk management. National Academy Press. 356 p.

Office of Technology Assessment. 1993. Harmful non-indigenous species in the United States. U.S. Congress. 391 pp.

Orr, R.L., S.D. Cohen, R.L. Griffin. 1993. Generic Non-Indigenous Pest Risk Assessment Process. USDA Report. 40 pp.

Risk Assessment Forum. 1992. Framework for Ecological Risk Assessment. U.S. Environmental Protection Agency/630/R-92/001.

Risk Assessment and Management Committee. 1996. Report to the Aquatic Nuisance Species Task Force: Generic Nonindigenous Aquatic Nuisance Species Task Force (For estimating risk associated with the introduction of nonindigenous aquatic organisms and how to manage for that risk). Aquatic Nuisance Species Task Force.

Ruiz, G.M., J.T. Carlton, E.D. Grosholz, and A.H. Hines. 1997. Global invasions of marine and estuarine habitats by non-indigenous species: mechanisms, extent, and consequences. American Zoologist **37**: 621-632.

United States Department of Agriculture APHIS. 1992. Plant protection and quarantine requirements for the importation of Pinus radiate and Douglas-fir logs, lumber, and wood chips from New Zealand. Draft document for mitigation requirements for and Interim Rule.

United States Department of Agriculture Forest Service. 1991. Pest risk assessment of the importation of larch from Siberia and the Soviet Far East. Miscellaneous Publication number 1495.

Vitousek, P.M., C.M. D'Antonio, L.L. Loope, M. Rejmanek, R. Westbrooks. 1997. Introduced Species: A significant component of human-caused global change. New Zealand Journal of Ecology. **21**: 1-16.