Written Testimony of

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To the

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I am a Senior Scientist at the Smithsonian Environmental Research Center (SERC), located on the shore of Chesapeake Bay. I have studied invasions for 15 years, and I head the Marine Invasion Research Laboratory – the largest research program in the U.S. to focus on the invasion of coastal ecosystems by non-native species. This research group provides synthesis, analysis, and interpretation of invasion-related patterns on a national scale (see Appendix 1 for further details).

Today, I wish to highlight briefly the current state of knowledge surrounding invasions of marine and aquatic ecosystems. I also wish to review some key gaps in our understanding that limit efforts to reduce the risk and impacts of invasions. I will focus particular attention on the importance of tracking invasion patterns and rates --- as the fundamental building block for invasion science and management --- without which we are left guessing about (a) the status and trends of invasions in the country and (b) the effectiveness of management strategies to stem the flow of new invasions.

Current State of Knowledge

Biological invasions are a major force of change. Invasions occur when species establish self-sustaining populations beyond their historical range, usually as an unintended consequence of human-aided transfer. Once established, these non-native or nonindigenous species can spread and achieve high abundances. A subset of invasions has strong effects, driving significant ecological changes and impacting many dimensions of human society on local, regional, national, and global scales.

Nonindigenous species (NIS) affect myriad aspects of aquatic (including freshwater and marine) ecosystems throughout the world. For example, we know that over 500 NIS have become established in coastal marine habitats of North America, and hundreds of NIS can occur in a single estuary. Some coastal communities are now dominated by NIS in terms of number of organisms, biomass, and ecological processes. It is clear that invasions have caused dramatic shifts in food webs, chemical cycling, disease outbreaks, and commercial fisheries. Some invasions also directly affect human health.

Chesapeake Bay and San Francisco Bay illustrate the status of NIS in marine communities. Over 150 NIS are established in tidal waters of the Chesapeake, based upon our research, and a larger number (>200 NIS) are reported for tidal waters of San Francisco Bay. Although the impacts of many species are not known, some are well documented, underscoring the magnitude and diversity of effects.

In the Chesapeake: The nutria, a South American mammal, is destroying salt marshes; the protistan parasite Haplosporidium nelsoni (also known as MSX), introduced from the Pacific, has contributed to the

demise -- and undermines recovery efforts for -- the native oyster fishery; several additional nonindigenous species, including submerged plants, hydroids, and clams, have clogged waterways and water intakes for power plants.
In San Francisco Bay & Delta: Multiple species of Spartina, an emergent salt marsh plant, are crowding out and hybridizing with native marsh plants, affecting key habitat for many animals; the Asian clam Potamocurbula amurensis has altered the species composition and abundance of plankton communities through filter-feeding; the Chinese mitten crab Eriochir sinensis has impacted water management by pumping facilities, when high numbers of migrating crabs clog associated fish collection screens.

The rate of newly detected marine invasions has increased exponentially over the past two hundred years for North America, as well as each Chesapeake Bay and San Francisco Bay. A similar rate increase has been observed across many habitats, taxonomic groups, and global regions. This apparent increase in invasion rate -- combined with observed impacts -- has greatly elevated public and scientific concerns about invasions in recent years.

Each year, thousands of nonindigenous species are still transferred to U.S. waters by human activities. A variety of mechanisms (vectors) contribute to this transfer process, which is the precursor to invasions. Among these, transfer of organisms by ships is considered responsible for most marine invasions in North America – both historically and currently. However, the relative importance of different vectors is likely to vary among locations, such as particular bays and estuaries.

Left unchecked, the number, density, and rate of species transfers – primary drivers of invasions -- are expected to increase. As a result of Congressional legislative action in 1990 and 1996, we have learned a great deal about the scope of the problem. Several efforts have advanced to reduce the likelihood and impacts of further invasions – implemented by multiple federal agencies, the Aquatic Nuisance Species Task Force, and a wide range of partnerships with state, university, and private entities. However, the problem is complex, involving thousands of species and many vectors that interface with multiple dimensions of society. The door is still open for new invasions to arrive, and further steps are clearly needed.

Vector Management

One clear priority is prevention of new invasions through vector management. Although management and control of established invasions can have merit, the approach and success of such efforts are often idiosyncratic to the particular invasion. Importantly, it remains difficult to predict (a) which NIS will be delivered, of a potential species pool of literally thousands of species that can be delivered by a vector (e.g., ballast water of ships), and (b) which NIS will become “invasive” and have severe impacts. This latter is particularly problematic, due to very limited information about the biology and ecology of the majority of marine organisms. In contrast, strategies to prevent new invasions can be directed at key transfer mechanisms (or vectors), the sources for contemporary invasions. Unlike management of established invasions on a species-by-species basis, a strategy of vector management can simultaneously prevent many new invasions through interruption of the transfer process.

Vector management involves three fundamental components: Vector Strength, Vector Analysis, and Vector Disruption. First, an assessment of Vector Strength is required to identify the relative importance of various vectors. This is accomplished by analysis of data on the patterns and rates of invasion, identifying which vectors are responsible for invasions (i.e., the relative importance of different vectors in space and time). Second, Vector Analysis is needed to describe the operational aspects of how, where, when, and in what quantity a vector delivers viable organisms (propagules) to the recipient environment. Among other things, this component identifies potential targets for management action. Third, some form of Vector Disruption is designed and implemented to restrict the flow of propagules (i.e., reduce the risk of new invasions) to the recipient environment.

Management of the shipping vector is a critical first step, to reduce aquatic invasions and their impacts. This recognizes the overall dominance of shipping in the transfer and invasion by NIS. Efforts being advanced for ballast water management should reduce the rate of invasions but there are limitations and unknowns in this area:

Among these --- the reduction in invasions expected for various management actions is unknown, resulting from uncertainty about the dose-response relationship (see below). We simply don’t know “how low to go” in reducing species transfer --- which complicates identification of the goal or “standards” for treatment.

Tracking invasions, through standardized field surveys, is of paramount importance to vector management, both to measure Vector Strength --- or the source of new invasions ---and to assess the long-term effect of Vector Disruption on invasion rates and patterns. I wish to focus my testimony on the role and status of contemporary surveys in vector management, and as a source of additional information for rapid response and various control measures.

Rationale for Measuring Invasion Patterns & Rates

Measuring invasion patterns and rates through regular, standardized, field-based surveys is the cornerstone of invasion science and invasion management. Without this information base, many fundamental questions in marine invasion ecology will remain unresolved, limiting advances for basic science as well as its ability to guide effective management and policy.

Only contemporary, standardized field measures can inform us about (a) the spatial patterns and tempo of invasion --- the where, when, and how of invasions ---, and (b) the efficacy of Vector Disruption to reduce new invasions. Knowledge about contemporary patterns of invasion is needed to guide efficiently and effectively our management and policy decisions. Identifying which NIS invade and their attributes are critical to development of predicative capability. Importantly, tracking invasions pattern, and especially long-term changes in invasion rate in association with Vector Disruption efforts, is essential for adaptive management --- testing for the desired effect of management action and whether further adjustments are required.

More specifically, such field-based measures are necessary to address the following questions:

· Are invasion rates changing over time?

· How does invasion risk (i.e., rates and extent of invasion) vary among regions?

· Are all regions equally susceptible to invasion?

· What factors influence susceptibility and risk of invasion?

· What characteristics are associated with successful invasions?

· Using analysis of Vector Strength (above), which vectors and geographic regions are responsible for observed invasions? How is this changing over time?

· Is there measurable change in the rate of new invasions that corresponds to management actions (i.e., Vector Disruption, above)?

· What is the quantitative relationship between species transfer (supply) and invasion rate, and what should the target or standard be for Vector Disruption (e.g., ballast water treatment)?

The latter two questions are particularly relevant to current discussion about standards or goals for Vector Disruption, such as ballast water treatment. The “dose-response” relationship -- between the number of propagules (organisms) released and invasion success (establishment) -- remains poorly resolved, yet understanding this relationship is key to developing effective standards and Vector Disruption. Field-based measures, combined with experiments, are necessary to understand this relationship. Moreover, only tracking of invasions through field-based measures can confirm the efficacy of Vector Disruption to reduce the rate of new invasions.

Although my primary focus is on use of field-based data for prevention, I also note the important role of such data for eradication and control efforts of established species. There has been considerable discussion in the past 2 years about development of an “early detection, rapid-response” capability in response to new invasions or outbreaks (e.g., see recent report by the General Accounting Office). Although the scope of this may vary, focusing only a subset of target NIS, any rapid-response system by definition relies upon an effective field-based detection system.

Status of Tracking Invasion Patterns & Rates

Numerous analyses now exist to describe patterns of invasion. These analyses result primarily from literature reviews, providing a synthesis of published reports. The Smithsonian Environmental Research Center (SERC) has developed the National Database of Marine and Estuarine Invasions, to summarize

existing data on marine invasions. The U.S. Geological Survey (USGS) has developed a complementary national-level database for freshwater invasions. Under a Cooperative Agreement, SERC and USGS are coordinating the further development of these databases, along with analyses and electronic access of the resulting information.

Although these existing “ecological surveys” have been very instructive in highlighting the scope of invasions in aquatic and marine habitats, the specific patterns and rates must be viewed with a great deal of caution --- because the data include very strong temporal and spatial biases. This bias results especially from uneven collection effort and taxonomic expertise. In essence, the data used in these analyses are “by-catch” and have limitations, as they were not collected for this purpose. A review of these issues is presented in a recent article entitled “Invasion of Coastal Marine Communities in North America: Apparent Patterns, Processes, and Biases” (Annual Review of Ecology and Systematics 2000, Vol. 31: 481-531).

Although existing syntheses provide useful information and apparent patterns, the information quality is insufficient to support robust conclusions about actual rates and patterns. This creates a fundamental weakness in our ability to guide and evaluate management efforts. In essence, we cannot address the questions outlined above with the existing data. For example, we cannot now estimate the rate of new invasions, or whether more invasions have occurred, at Tampa Bay (FL), Juneau (AK), Chesapeake Bay (MD/VA) or Port Arthur (TX).

The National Invasive Species Act of 1996 called for “ecological surveys” to better understand the patterns of invasion. Multiple such surveys have occurred, and these have provided some important insights about the extent of invasions. However, to date, these surveys suffer from the same issues as outlined above, because they have been primarily literature-based surveys.

At the present time, there exists no national program designed to collect the type of standard, repeated, quantitative, and contemporary measures across multiple sites that is needed to measure rates and spatial patterns of invasion. Although this has been evident for many years, and was the focus of a workshop in 1998 (sponsored by U.S. Fish & Wildlife Service and SERC, and presented to the Aquatic Nuisance Species Task Force), a program to address this gap has not emerged to date. Importantly, piecing together data from existing programs, as has been suggested, will likely suffer limitations --- similar to those that exist today --- because these programs were not designed explicitly to measure invasion patterns.

Most recently, SERC has initiated a series of quantitative surveys across 15-20 different bays in North America, focusing on sessile invertebrates. Funded by Department of Defense, National SeaGrant, and U.S. Fish & Wildlife Service, this work is intended to compare pattern of invasions among sites, using one standardized survey (in one year) at each bay. Although this is not presently a sustained effort, it moves toward developing a quantitative baseline, and could serve as a prototype for repeated, temporal measures.

Approach to Track (Monitor) Invasions

To effectively measure invasion patterns and rates, as needed to address the questions outlined above, requires the use of standardized, quantitative surveys that are replicated at many sites and repeated regularly over time. Multiple sites are necessary, because significant variation exists among sites --- such that one or a few sites cannot serve as a proxy for others --- but also because measures of such spatial variation is necessary to test for (a) spatial variation in invasibility and (b) the relationship between propagule supply and invasion. Further, repeated measures are necessary to build statistical confidence about the existing assemblage of species (or develop a baseline) with which to measure temporal changes.

Oversight and coordination of the surveys is critical to develop standardized protocols, provide continuity in taxonomic identification, and manage, analyze, and interpret the resulting cumulative data. Without such oversight, as is presently the case, measures of invasion patterns and rates will remain uneven and cannot contribute to a larger picture (beyond an individual site) or be used to address questions (as above) on a national scale.

Beyond the specifics of survey design and implementation, parallel measurements of environmental characteristics of surveyed sites is also key to understanding those factors that influence susceptibility (risk) to invasion. While direct measures of physical and chemical characteristics are necessary to provide standardization across sites, there are several existing programs that may prove valuable sources of this information. For example, the EPA is characterizing many aspects of shoreline habitats, and especially coastal wetlands, in Chesapeake Bay. NOAA and EPA have also both developed networks of coastal sites

that collect data on physical and chemical environmental attributes.

Conclusions

Understanding invasion patterns and processes depends critically upon high-quality empirical measures. Current observation and theory have resulted in a conceptual framework for invasion ecology. However, the empirical data needed to rigorously test many key hypotheses, develop robust predictions, and evaluate the success of management actions lag far behind. This gap is especially conspicuous for marine systems, existing both in the quality and quantity of descriptive data. At the present time, most analyses that evaluate patterns of invasion or test specific hypotheses derive data from the existing literature, or “by-catch” data, which is extremely uneven in space and time. Quantitative field surveys, which employ standardized and repeatable measures, are critically needed to remove such bias and to substantively advance invasion science and management.

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EDUCATION:

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FIELDS OF INTEREST:

Invasion Biology; population and community ecology; ecological parasitology and the role of parasitism in host evolution; predator-prey interactions; larval recruitment of marine invertebrates.

PROFESSIONAL HISTORY:

1989-Present Senior Scientist, Smithsonian Environmental Research Center, Smithsonian Institution.

1993-Present Participating Faculty Member, MEES Program, University of Maryland.

1996-2000 Consultant in Research, Department of Biological Sciences, George Washington University.

1988-1989 Postdoctoral Research Associate, Oregon Institute of Marine Biology, University of Oregon.

1987-1988 Postdoctoral Research Associate, Friday Harbor Laboratories, University of Washington.

SELECTED RECENT PUBLICATIONS (of 45 total):

Ruiz GM & CL Hewitt. 2002. Toward understanding patters of coastal marine invasions: a prospectus. In: Invasive aquatic species of Europe (E Leppakoski, S Olenin, & S Gollasch, eds.), Kluwer Academic Press.

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Smith, L.D., M.J. Wonham, L.D. McCann, G.M. Ruiz, A.H. Hines and J.T. Carlton. 1999. Invasion pressure to a ballast-flooded estuary and an assessment of inoculant survival. Biological Invasions 1:67-87.

OTHER PROFESSIONAL ACTIVITIES:

Committees: U.S. representative to the Working Group on Introductions and Transfers of Marine Organisms, International Council for the Exploration of the Sea (2001 to present); Scientific & Technical Advisory Committee, U.S. EPA Chesapeake Bay Program (2001- present); Steering Committee for Global Invasive Species Program (1999-2000); Advisory Committee for National Aquatic and Marine Invasion Clearinghouse (1999 to present); Ballast Water Work Group, Chesapeake Bay Commission (1994); Exotic Species Work Group, U.S. EPA Chesapeake Bay Program (1994 to present); Ballast Water and Shipping Committee, Aquatic Nuisance Species Task Force (1997-2001); Steering Committee for Marine Bioinvasions Conference (1999, 2001).

APPENDIX 1

Role of the Smithsonian Institution in Coastal Invasion Research:

Marine Invasion Research Laboratory,
Smithsonian Environmental Research Center
(August 2002)

Overview

The Smithsonian Environmental Research Center (SERC), located on the shore of Chesapeake Bay, is a leading national and international center for research in the area of non-native species invasions in coastal ecosystems.

SERC has developed the largest research program in the U.S. to focus on coastal invasions.

A primary goal of SERC's Marine Invasion Research Laboratory is to provide the fundamental science that is critical to develop effective management and policy in this topic area. In short, SERC's invasion research bridges the gap between science and policy, to develop a scientific understanding that is key to guide and evaluate management strategies for invasive species.

The Marine Invasion Research Laboratory has a staff of approximately 30 biologists, who conduct research throughout the country and overseas. Since it's inception 10 years ago, the laboratory has been a nationwide training center in invasion ecology for roughly 45 technicians, 4 graduate students, 7 postdoctoral researchers, and 40 undergraduate summer interns. The students and technicians arrive from all over the country, staying for 3 months to many years. Many participants in this program have gone on to graduate training and academic or government positions in Alabama, California, Connecticut, Hawaii, Massachusetts, Tennessee, and Washington, Washington D.C.

Research Program

As a national center, SERC's Marine Invasion Research Laboratory provides synthesis, analysis, and interpretation of invasion-related patterns for the country. Under the National Invasive Species Act of 1996,

the U.S. Coast Guard and SERC created the National Ballast Water Information Clearinghouse, hereafter Clearinghouse, to collect and analyze national data relevant to coastal marine invasions (see Box 1). Established at SERC in 1997, the Clearinghouse measures:

· Nationwide Patterns of Ballast Water Delivery and Management. All commercial ships arriving to all U.S. ports from overseas report information about the quantity, origin, and possible control measures for their ballast water - a primary mechanism for transfer of non-native marine species throughout the world. At present, SERC receives roughly 20,000 such reports per year. Every two years, SERC provides a detailed analysis and report to U.S. Coast Guard and Congress on the patterns of ballast water delivery by coastal state, vessel type, port of origin, and season. A key issue is the extent to which ships undertake ballast water exchange, a management technique to flush potential invaders out of the tanks prior to arrival in U.S. waters. SERC's analyses are used by U.S. Coast Guard and Congress to assess national needs with respect to ballast water management and to track program performance.

· Rates and Patterns of U.S. Coastal Invasions. SERC has developed and maintains a national database of marine and estuarine invasions to assess patterns of invasion in space and time. This database compiles a detailed invasion history of approximately 500 different species of plants, fish, invertebrates, and algae that have invaded coastal states of the North America. Among multiple uses, the database identifies which species are invading, as well as when, where, and how they invaded; it also summarizes any existing information on the ecological and economic impacts of each invader. Over the long-term, this database will help assess the effectiveness of various management strategies (such as ballast water management, above) in reducing the rate of invasions. More broadly, this information is a valuable resource for many user groups --- from resource managers and scientists to policy-makers and industry groups.

Box 1

Except from the National Invasive Species Act of 1996

NATIONAL BALLAST INFORMATION CLEARINGHOUSE-

(1) IN GENERAL- The Secretary shall develop and maintain, in consultation and cooperation with the Task Force and the Smithsonian Institution (acting through the Smithsonian Environmental Research Center), a clearinghouse of national data concerning--

(A) ballasting practices;

(B) compliance with the guidelines issued pursuant to section 1101(c); and

(C) any other information obtained by the Task Force under subsection (b).

(2) REPORT- In consultation and cooperation with the Task Force and the Smithsonian Institution (acting through the Smithsonian Environmental Research Center), the Secretary shall prepare and submit to the Task Force and the Congress, on a biannual basis, a report that synthesizes and analyzes the data referred to in paragraph (1) relating to--

(A) ballast water delivery and management; and

(B) invasions of aquatic nuisance species resulting from ballast water.

SERC has further expanded the scope of Clearinghouse activities to improve the quantity and quality of data on coastal marine invasions that are used to (a) assess the rates and patterns of invasion and (b) inform key management decisions at national, regional, and local levels. Through competitive grants, we have initiated two components in this area, including:

· Nationwide Field Surveys. SERC has implemented an ambitious program of field surveys to detect new invasions, as well as measure contemporary patterns and effects of invasions, for 15-20 different bays throughout the country (see Figure 1). Our intent is to expand this program to include additional regions, providing a national baseline of information with which to evaluate invasion rates. The resulting information will contribute to the national database (above) and will be used both to document patterns of invasion and to assess the effects of management on invasion rates (as discussed above).

· Comprehensive National Database. SERC has established a formal agreement (Memorandum of Understanding) with the U.S. Geological Survey's Caribbean Research Center to develop a comprehensive database of all freshwater and marine invasions in the United States. SERC maintains a database of exotic marine species (above), and the U.S.G.S. maintains a complementary database for exotic freshwater species. Our goal is to functionally link these databases, creating web-based access to key information about each species for managers, researchers, policy-makers and the public.

In addition to the Clearinghouse role of analysis and interpretation of national data, SERC also conducts research to understand underlying mechanisms of species transfer, invasion, and ecological effects of invasions. This research serves a dual purpose of advancing our fundamental knowledge of invasion processes and using this knowledge to improve prediction and management strategies for invasions. Some selected examples of our research in these areas, funded by external grants and contracts, include:

· Measuring the Patterns and Processes of Species Transfer Associated with Shipping. The Marine Invasion Research Laboratory has measured the density and diversity of organisms in the ballast water of approximately 450 different commercial vessels, primarily oil tankers and bulk cargo carriers that arrived to Chesapeake Bay and Port Valdez, Alaska. This has been a collaborative and cooperative research program with the shipping industry, over the past 8 years, to better assess the risks of invasion and effectiveness of various management techniques to reduce that risk. We are now expanding this research to include container ships arriving to San Francisco Bay, expanding existing measures to include a different vessel type and geographic region than the previous studies.

· Assessing the Magnitude and Consequences of Pathogenic Microorganism Transfer by Ships. Very little is known about the relative risks of pathogens, both for humans and commercially important species, which are transferred in ballast water. SERC's invasion program is measuring the concentration of microorganisms and human pathogens, including Vibrio cholerea (causitive agent of epidemic human cholera), discharged into U.S. waters with the ballast water of ships. In addition, we are conducting experiments to test the viability and potential significance of these transfers to result in newly established populations, or invasions, of pathogenic organisms.

· Measuring the Ecological Impacts of Non-Native Species. SERC has implemented a broad range of field-based and experimental studies to measure the effects of marine invasions in coastal ecosystems, including impacts on commercial fishery resources. Much of this work to date has focused on the European green crab (Carcinus maenas) impacts in California and New England. We have also implemented experiments in California and Virginia to test for effects of particular fouling organisms on invaded communities, and the extent to which this is exacerbated by human disturbance (e.g., pollutants, hypoxia, etc.). The overall goal of work in this area is to understand and predict impacts of invasions across a diverse array of coastal communities.

· Testing Invasibility of Communities. We have just begun manipulative laboratory and field experiments to test environmental and biological factors that influence invasibility of marine communities. Our work in this area focuses on microorganisms and invertebrates. The main objective of this research is to measure the dose-response relationship between delivery of organisms and subsequent invasion, and how this may vary across different environmental and biological conditions. This approach has direct bearing on the effect (and target) for management strategy to reduce the delivery of non-native organisms by ships or other vectors.

· Feasibility of Eradication and Control of Established Marine Invasions. SERC has also initiated work to test the feasibility of eradication and control for a non-native marine snail in San Francisco Bay. This is effectively a demonstration project to critically examine management strategies, based upon key habitat and biological characteristics, and develop the decision process (i.e., under what conditions and for which species) and capacity for eradication.

Geographic Coverage

SERC's Marine Invasion Research Laboratory, with staff based at Chesapeake Bay and San Francisco Bay, has established research sites throughout the U.S. to implement its research programs, in collaboration with researchers from approximately 25 different academic institutions and federal or state agencies. For example, active projects and collaborations are on-going in the following states: Alaska, California, Connecticut, Florida, Maine, Maryland, Massachusetts, Michigan, New Jersey, Oregon, Rhode Island, Texas, Virginia, Washington, and Washington D.C.

Internationally, SERC has become increasingly active over the past 5 years. A primary goal of the international program is to foster information exchange and build complementary, comparative, and collaborative research programs. For example, the Marine Invasion Research Laboratory has active collaborations in many areas of invasion ecology with the Centre for Research on Introduced Marine Pests (CSIRO, Australia). This includes comparative analyses of invasion patterns and effects, as well as development of an international standard for databases on marine invasions. Another long-term collaboration exists with scientists in Israel, where we have measured changes in the ballast water communities during roughly 20 different voyages between Israel and Chesapeake Bay. SERC also has been a participant and sponsor of international conferences and workshops on marine invasion ecology.

Although SERC programs are active at the national and international scales, a great deal of this effort has also focused on understanding invasion issues at the regional scale. In fact, this program has conducted research on invasions in nearly every coastal state in the country, producing regional understanding as well. Examples include:

· Analysis of invasion patterns for Chesapeake Bay over the past 400 years, representing the first such analysis for the Chesapeake as well as any estuary in the eastern U.S. This documents the invasion history of 160 non-native species established in this Bay.

· Analysis of extent of invasions for Prince William Sound, Alaska, providing the most detailed analysis in the world to assess the risks of invasion for a high-latitude system.

For More Information about the Marine Invasion Research Laboratory contact:

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Portsmouth Harbor

Chesapeake Bay

Jacksonville

Tampa Bay

Pensacola

Puget Sound

Coos Bay

San Francisco

Bay

San Diego

Prince William Sound

Kachemak Bay

Galveston

Corpus Christi

SERC Marine Invasion Research Sites

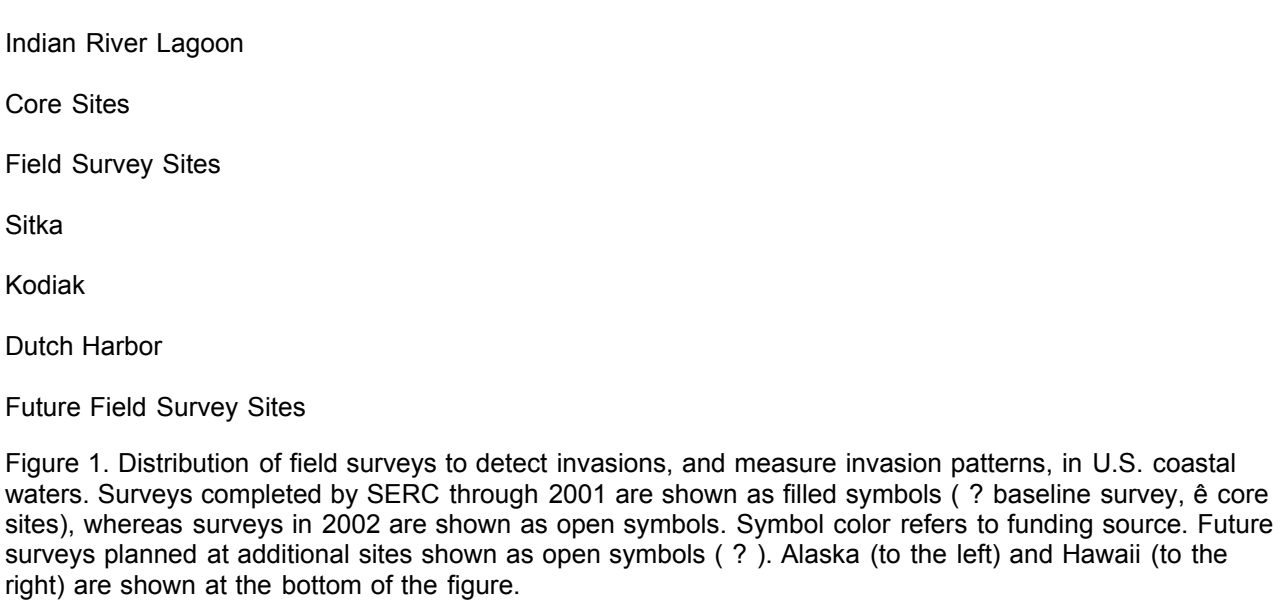

Figure 1. Distribution of field surveys to detect invasions, and measure invasion patterns, in U.S. coastal waters. Surveys completed by SERC through 2001 are shown as filled symbols (? baseline survey, ê core sites), whereas surveys in 2002 are shown as open symbols. Symbol color refers to funding source. Future surveys planned at additional sites shown as open symbols (?). Alaska (to the left) and Hawaii (to the right) are shown at the bottom of the figure.