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Good morning and thank you for the opportunity to be here today.

My name is Gregory Ruiz. I am a Senior Scientist at the Smithsonian Environmental Research Center (SERC), located on the shore of Chesapeake Bay.

SERC is a leading national and international center for research in the area of non-native species invasions in coastal ecosystems. I head the Marine Invasion Research Laboratory based in Maryland. The Laboratory also maintains resident staff and research facilities in California and Oregon. Collectively, this group provides synthesis, analysis, and interpretation of invasion-related patterns on a national scale.

A primary goal of SERC's research on non-native species invasions is to advance the fundamental science, which is critical to developing effective management and policy in this area. Our research aims to address gaps between science and policy, providing the needed scientific understanding to inform and evaluate management strategies for invasive species.

Today, I wish to highlight briefly the current state of knowledge about invasions for marine and aquatic ecosystems, considering Chesapeake Bay and the Nation more broadly. I also wish to focus particular attention on (a) the importance of tracking invasion patterns and trends – as a critical building block of invasion science and management, and (b) the need for vector-based management to reduce the risk and impacts of invasions.

Current State of Knowledge

Biological invasions, the establishment of non-native or nonindigenous species outside of their historical range, are rapidly changing the earth's marine and freshwater ecosystems. A growing number of natural communities are dominated by non-indigenous species (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.

The cost of invasions to society is enormous, including loss of crops and fisheries, damage to infrastructure and water supplies, and effects on human health. One estimate is that invasions cost the United States approximately $137 billion per year in losses and damages (Pimentel et al., Bioscience, 2000). Although the impacts of most invasions remain unexplored, ***there is no doubt that biological invasions have become a major force of ecological change, as well as economic and human health impacts, operating on local to global scales.***

Coastal bays and estuaries are especially vulnerable to invasion by non-native species. This is exemplified by Chesapeake Bay, the Nation's largest estuary. SERC's research has documented 177 NIS that have established, self-sustaining populations in tidal waters of the Chesapeake. Over the past century, the rate of detected invasions has increased dramatically. These organisms have been delivered here by a diverse range of human-mediated transfer mechanisms (vectors), including shipping and fisheries activities. The Chesapeake invaders arrived from throughout the world, reflecting the global scale of commerce and connectivity. [Additional detail on the invasion history for Chesapeake Bay is included in Appendix 1 and is also available online through the National Exotic Marine and Estuarine Information System (NEMESIS; http://invasions.si.edu/nemesis/cbsearch.html.)]

Some invasions have large effects on the Chesapeake Bay, in terms of both the natural resources and society. Examples of high-impact species occur across taxonomic groups and habitats, arriving by multiple vectors:

- The oyster parasite MSX (*Haplosporidium nelsoni*) causes mass mortality of the native Eastern oyster, contributing to the collapse of Chesapeake's iconic fishery and undermining efforts for its recovery. The parasite first appeared in the mid-20th century. It is native to Asia, where it infects oysters, and was apparently transferred to the mid-Atlantic region either by importation of infected (nonindigenous) oysters or associated with the hulls or ballast water of vessels arriving from Asia.
- The nutria (*Myocastor coypus*) is responsible for destruction of salt marsh habitat, converting marsh to bare mud and open water and removing critical habitat for waterfowl, fish, and other organisms. This mammal was brought to the region for fur production and became established in the 1940s due to both escapes and intentional releases. Native to South America, this species is the focus of active eradication efforts in the Chesapeake Bay.
- A Eurasian genotype of the common reed (*Phragmites australis*) forms dense, mono-specific stands that crowd out native marsh vegetation and affect fish and other wildlife. The introduced plant was present in the Chesapeake by the late 19th century and was delivered unintentionally in dry ballast of ships or in agricultural products. Unlike the native genotype (which was historically uncommon), this invader occupies large areas and is continuing to spread aggressively in Chesapeake Bay and elsewhere along the Atlantic coast. Various local efforts have existed to control the species and limit its spread in the Chesapeake.

Also of great concern is the observed increase in new invasions for the Chesapeake. On a daily basis, NIS are delivered to our shores by many different human-mediated activities, such as the movement of ships, recreational vessels, and live trade organisms (seafood, bait, aquaria pets, plants). These operate to transfer NIS on a global scale. As a result, we see new invasions occurring, such as the Chinese Mitten Crab (*Eriocheir sinensis*), which we are finding (only since 2005) in Maryland, Delaware, New Jersey, and New York waters. Listed as "injurious wildlife" by the U.S. Fish and Wildlife Service under the Lacey Act, this species has caused significant problems with water management in the San Francisco Delta of California, where it is also established and undergoes "outbreaks" of high abundance.

The Chesapeake Bay serves as a model for what is occurring throughout the Nation. Marine and freshwater invasions are having significant ecological and economic impacts in many other regions. This issue has sparked great concern in many states. On a national scale, like the Chesapeake Bay, our research indicates that the rate of newly detected invasions is increasing through time. This means that the impacts of invasions are increasing through time, due to combined effects of (a) those high-impact species already established and (b) new species that continue to accumulate, which will surely include some proportion of high-impact species.

Invasions pose a significant challenge for resource management and restoration efforts, due to the scale and often unpredictable nature of associated impacts. This is further exacerbated by the growing number of NIS and also climate change. Increasing temperature will serve to expand the number of NIS that can colonize, by creating suitable conditions for survival and reproduction that did not previously exist. Changing conditions will also allow some established species to exert stronger effects than is currently the case. However, one of the biggest challenges of shifting climate regime is the associated uncertainty of ecological consequences, and much work is needed to predict effects on invasion dynamics.

There are two key steps needed to address invasion impacts. The first is to reduce the risk of future invasions by preventing establishment of new species. The second is to mitigate the effects of NIS that have already colonized, using available control or eradication methods for selected, high-impact species. These are best pursued concurrently. However, unless we address the increasing supply of new invaders, our ability to mitigate for established invasions on a species-by-species basis is rapidly overwhelmed, especially since difficult choices are already being made about how to allocate limited resources for control and eradication.

Vector Management to Prevent Invasions

One clear priority for the Nation is vector management to greatly reduce the risk of new invasions. The continued introduction of new NIS is often viewed as a "surprise", one species after another, and year after year, but these invasion events are not unexpected. Each new invasion is a warning signal, telling us that the vector is operating and the door is open for new invasions. Instead of responding individually to each introduced species as a novel occurrence, a strategy of vector management seeks to simultaneously prevent invasions by many species through interruption of the general 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 approaches for management action. Third, some form of Vector Disruption is designed and implemented to restrict or stop the flow of propagules (i.e., reduce the risk of new invasions) to the recipient environment. [This framework is presented in the following book chapter: Ruiz GM & JT Carlton. 2003. Invasion vectors: a conceptual framework for management. In: *Invasive Species: Vectors and Management Strategies*, GM Ruiz and JT Carlton (editors), pp. 459-504. Island Press, Washington.]

There is still considerable work to be done to achieve effective vector management. The Nation's current approach to vector management is a patchwork, applied inconsistently across different vectors, rather than a coherent and effective policy. For some vectors, such as ships' ballast water, a vector management framework (including vector disruption) is being implemented. For others, such as transfer of live aquatic organisms or coastal movement of recreational vessels, vector management is poorly developed.

There are also critical scientific gaps that limit vector management. One of the most critical gaps is in tracking or measuring the occurrence of invasions over time. Remarkably, there exists no national program designed to collect the type of standard, repeated, and quantitative measurements needed to assess status and trends of coastal invasions in America. This presents significant problems for vector management, as outlined below.

The Importance of Tracking (Measuring) Invasions

Tracking invasion 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. Measuring invasion occurrences, patterns and rates is the cornerstone of invasion science and invasion management. Without a reliable 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 rigorous, standardized and repeated 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 and emerging patterns of invasion is needed to guide management and policy decisions. 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 broadly, measuring invasion occurrence is at the core of several management goals. In addition to the direct application for identification and management of vector activity, occurrence records are critical for modeling and predicting invasion risk, spread, and impact. The technical capacity exists to develop predictions, but applications are often limited by sufficient occurrence data. Occurrence data are also necessary for eradication and control efforts of established species. There has been considerable discussion in recent years about development of an "early detection, rapid-response" capability in response to new invasions or outbreaks. Although the scope of this may vary, from attention to a small subset of species to a wider spectrum of potential invasions, ***any rapid-response system by definition relies upon an effective field-based detection system.***

Status of Tracking (Measuring) Invasion Patterns & Rates

Numerous analyses now exist to describe patterns of marine invasion in the United States. These analyses result primarily from literature reviews, providing a synthesis of published reports. ***Although existing syntheses provide useful information and apparent patterns, the information quality is insufficient to support robust conclusions about actual rates and patterns, including especially current trends associated with specific vectors.***

Current analyses provide a minimum estimate of established marine non-native species in U.S. estuaries. Many regions, habitats, and taxonomic groups have simply not been surveyed in recent time, providing only a partial picture of contemporary invasion dynamics. Thus, emergent patterns and rates must be viewed with a great deal of caution --- because the data include very strong temporal and spatial biases. These biases result especially from uneven or haphazard collection effort. ***In essence, the data used in most 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).

SERC has developed the National Exotic Marine and Estuarine Species Information System (NEMESIS) to summarize existing data on marine invasions. The U.S. Geological Survey (USGS) has developed the Nonindigenous Aquatic Species database, 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.

However, at the present time, ***there exists no national program designed to collect the type of standard, repeated, quantitative, and contemporary field-based 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 inter-agency Aquatic Nuisance Species Task Force), a program to address this gap has not yet emerged. Importantly, piecing together disparate data from existing programs, as has been suggested, will suffer limitations --- similar to those that exist today --- because these programs were not designed explicitly to measure invasion patterns.

Most recently, SERC has implemented a series of quantitative surveys across 26 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 a single 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 (Measure) Invasions

To effectively measure invasion patterns and rates for vector management 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. For example, invasions in Chesapeake Bay may differ greatly from those in San Francisco Bay, Columbia River, Raritan Bay, Narragansett Bay, or Tampa Bay. 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.

As a minimum, one lead group should be charged with oversight and coordination of the surveys to develop standardized protocols, provide continuity in taxonomic identification, and manage, analyze, and interpret the resulting cumulative data. Without such oversight, 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 on a national scale.

Although I emphasize the importance of identifying a lead science group to coordinate and oversee surveys, providing many centralized services, ***a distributed network of research groups (including the lead group) may be the most effective model***. For example, the lead group could establish standard protocols, develop some demonstration sites, and serve to coordinate replicated surveys among the network of collaborating researchers (including those at universities as well as state or federal labs) who work at many sites throughout the country. Further, field-based surveys at each site could include some standardized core elements (i.e., identical across all sites) and possibly some measures that are of relevance or particular interest at only a subset of sites.

A distributed network would require clear and frequent communication across sites, to achieve coordinated and standardized measures. A clear advantage with such a network approach lies in the local implementation of surveys, drawing on local or regional expertise in a cost-effective manner. Further, ***the development of a distributed network with centralized services, including especially data management and analyses, would assure rapid access to current information --- which could inform analyses of invasion patterns and rates or rapid-response actions***. Further, such a distributed network is readily scalable, allowing for established links and coordination with many groups --- both nationally and overseas.

Beyond the specifics of survey design, there are many other elements that require attention, having important consequences for the possible analyses and interpretation, including: (i) taxonomic identification, (ii) reference material, (iii) geographical information, (iv) information management, and (v) environmental characteristics. One role of the coordinating group could be to implement standard protocols across each of these topic areas and also to develop partnerships with existing programs to contribute relevant expertise on physical, chemical, and biological dynamics of survey sites.

[Further background and discussion are included in the following book chapter: 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 (editors), p. 529-547. Kluwer Academic Publishers, Dordrect.]

Conclusions

Chesapeake Bay and estuaries throughout the country are experiencing significant impacts due to non-native species, and the rate of invasions appears to be increasing. Vector management to reduce invasion risk is a high priority for the Nation. Advancing scientific understanding and vector management for invasions depends critically upon high-quality empirical measures, which are now lacking. This gap is especially conspicuous for marine systems. Quantitative field surveys, which employ standardized and repeated measures, are needed to truly understand and effectively reduce invasion risk.