Aquatic Nuisance Species Research Program

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Utility of Niche Models in Developing Site Assessments Technologies Associated with Aquatic Nuisance Species Invasions at Corps Facilities

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Purpose

The rate of invasive species introductions into the United States has steadily increased over the past 20 years. Coupled with ever-increasing human activity has been a steady increase in movement of invasive species resulting in many introductions of species into new landscapes (National Invasive Species Council (NISC) 2001). These introductions can pose serious threats to U.S. Army Corps of Engineers (USACE) installations and projects and their impact is only expected to worsen. This article summarizes some new and novel approaches to invasion biology that can be used to predict species movements across broad geographic regions and local landscapes.

Background

In the early 1990's it was estimated that there were more than 4500 nonindigenous species in the United States (Office of Technology Assessment (OTA) 1993). Of these, approximately 15 percent were considered as causing serious harm. In 1993, there were estimated to be more than 154 aquatic nuisance species (ANS) in Florida's inland waters, more than 120 species in the Chesapeake Bay, more than 67 species in Coos Bay, OR, more than 139 species in the Great Lakes, more than 123 species in San Francisco Bay area, and more than 154 species in the Hudson River, NY (ANS Task Force; http://www.anstaskforce.gov). From these regions of initial introduction, some species, though not all, can be expected to move inland and extend their range throughout the continental United States.

By 1997 concerned scientists and resource managers began a campaign for action at the national level against invasive species (NISC 2001). As a result, President Clinton signed an executive order in 1999 "to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause" (Executive Order 13112, Federal Register 1999). Although funding was not included, the order laid the foundation for the development of programs that would prevent, plan, monitor, and study species invasions and each Federal agency was charged with developing programs compliant with the directives in the order.

One of the challenging aspects of invasion biology is predicting which species will invade and which invaders will become serious problems. The attributes of a successful invader have been well-documented. Invaders typically have a large native range where they are found in abundance, short generation time, broad diet, genetic variability, variable life strategies, and wide physiological tolerances (Ehrlich

1989). Until only recently computational tools for predicting invasions were insufficient to the task. Today, geographic information systems (GIS) have allowed researchers the capability of generating maps of species richness and endemism (Peterson et al. 2000) and occurrence data from a variety of sources are beginning to become more available due to internet-based technological developments (Peterson 2001). Finally, niche modeling programs that were originally developed for biodiversity informatics and quantitative geography have been found to have applicability to invasive species research (Peterson and Vieglais 2001).

This article summarizes the use of niche modeling for predicting species invasions. The potential to predict ANS invasions will be a significant aid in providing early warning to USACE personnel of site vulnerability and will allow for a more proactive approach in detecting, monitoring and combating specific species.

Overview of Niche Modeling

The concept of the niche was developed early in the 20th century (Grinnell 1917, Elton 1927). Grinnell (1917) defined a niche as all sites where a species can live and therefore was geographic in focus (Peterson 2003). Elton (1927) took a different approach and defined a niche as the function performed by a species in the community of which it is a member. Hutchinson (1959) expanded the idea and developed the concept of the "fundamental niche" as the range of possibilities in ecological space that a population could persist (Martinez-Meyer 2005). However, due to a variety of biotic and abiotic factors, species seldom occupy the entire fundamental niche and instead occupy what Hutchinson (1959) termed the "realized niche," i.e. that portion of the fundamental niche actually occupied by the species in geographic space. In the past 20 years, mathematical techniques have been developed that can estimate the geographic extent of the fundamental ecological niche and according to Soberón and Peterson (2005), it is this ability that provides an important intermediate step towards determining the geographic distribution of a species.

The distributional potential of a species in a new region can be predicted by detection of conditions that match the species ecological niche in its native range. Model processes involve three basic steps: 1) niches are modeled in ecological space; 2) the models are evaluated based on native distributions, and; 3) the models are then projected to areas that could be invaded (Peterson 2003, Martínez-Meyer 2005). At present, four computerized modeling methods that have commonly been used in biodiversity research also have potential for predicting species invasions over new geographic regions: bioclimatic envelopes, generalized linear models (GLMs), generalized additive models (GAMs), and genetic algorithms (GA) (Elith and Burgman 2002). The most commonly used modeling techniques have been the GLMs, and to a lesser extent, GAMs. In recent years more sophisticated models like the Genetic Algorithm for Rule-set Prediction (GARP) have been developed. GARP uses several distinct algorithms in an iterative, artificial intelligence based approach (Peterson 2001, Peterson and Vieglais 2001). A great advantage of GARP is that it reduces errors of omission (leaving out niche space that is really occupied by a species) and commission (including niche space not actually occupied by a species) (Peterson and Vieglais 2001). Finally the rule sets that are developed can be projected onto GIS coverage for regions of interest to predict geographic distributions of species. This tool offers great potential for developing site assessment modules for USACE facilities in that it can be used to predict invasive species ranges.

The GARP predictive models first relate ecological characteristics of known occurrence points of a species to randomly sampled points from the rest of the study region, then a series of decision rules are developed that summarize the factors associated with the species presence in an area (Feria and Peterson 2002, Peterson and Robins 2003). The occurrence points are divided into training and test data sets with 50 percent of the points set aside for an independent test of model quality (extrinsic test data), 25 percent are used for developing the models (training data), and 25 percent are used for tests of model quality (intrinsic test data) (Peterson et al. 2003). Maps are developed that show the species distribution in the native range and predicted occurrence of the species into a new region. The predicted ranges can be color-coded, denoting areas where the species has a high, medium, or low probability of invasion or where invasion is highly unlikely to occur.

Applications of Niche Modeling

To test the reliability of GARP for predicting species invasions, Peterson et al. (2003) ran models of four alien plant species (*Hydrilla verticillata* (L.f.) Royle, *Elaeagnus angustifolia* L., *Lespedeza cuneata* (Dum.-Cours.) G. Don, and *Alliaria petiolata* (Bieb.) Cavara & Grande) that have already invaded North America. As all four species are well-established in the United States their current distribution could easily be compared to the model prediction. In all cases the niche model predicted the extent of invasion of each species in North America with high accuracy. For example, the model predicted 201 of the 206 known county occurrences of *Alliaria petiolata* based on current distribution information contained in the USDA National Plants Database (http://plants.usda.gov/). The real value of the ability to forecast invasions is that it provides a strong basis for focusing monitoring efforts toward early detection of new invaders. Early detection and rapid response can be used to eradicate or contain an invasive species at a reduced cost compared to long-term control if the species becomes established and spreads (NISC 2001).

The recent use of GARP for predicting North American bass invasions into Japan clearly demonstrated the utility of the niche-modeling program (Iguchi et al. 2004). Of concern to the Japanese is that increased popularity of sport fishing will increase the range of largemouth and smallmouth bass, resulting in the displacement of native fishes, many of which are endangered. Knowing where the two bass species are most likely to invade in Japan has great significance because it will allow the appropriate agencies to take action either to stop or to mitigate the invasions. Using GARP, both the largemouth bass and the smallmouth bass were projected to invade over much of the Japanese archipelago (Iguchi et al. 2004). Using North American occurrence points, the predictive model of the largemouth bass showed a high degree of correspondence with known occurrences in Japan, indicating the utility of the model in predicting the potential range (Iguchi et al. 2004). This range included the island of Hokkaido where the species has yet to invade. Knowing the potential threat, actions can be taken to better monitor and prevent its introduction onto that island. Because the smallmouth bass is a recent introduction and currently has a limited distribution, the predictive model could not be evaluated as rigorously. However, based on the highly significant predictability of the largemouth bass distribution, confidence in the prediction of the potential distribution areas for smallmouth bass in Japan increased substantially. It

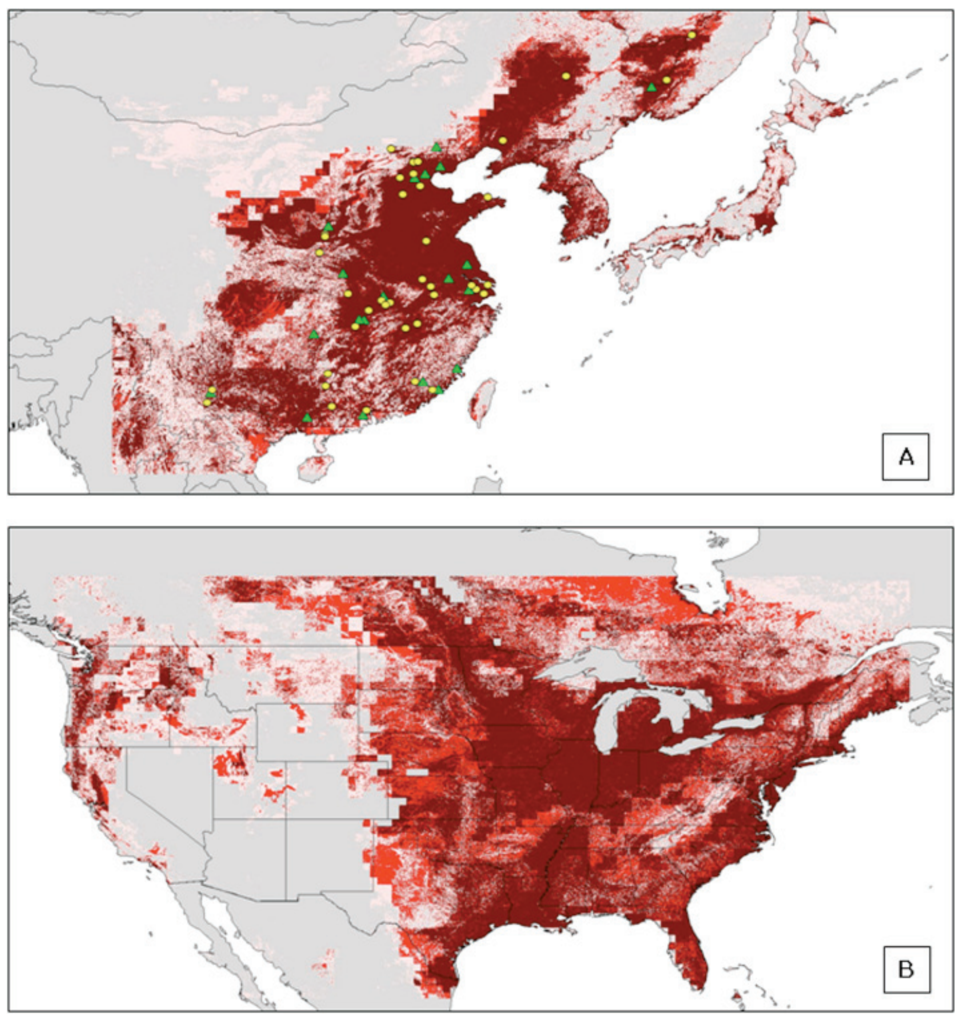

Figure 1. Geographic predictions for black carp in (A) Eastern Asia and (B) North America. Green triangles represent the intrinsic training data used to model the native distribution in Asia; yellow dots represent the extrinsic data used to test the native-range model. The maps are not to scale relative to each other. (GARP model courtesy of Kristina M. McNyset)

allowed for a proactive approach to invasion biology and through monitoring and early detection, the species was eradicated from several lakes in Japan (Iguchi et al. 2004).

A similar approach could be taken with an invasive fish species from Asia that has been introduced into the United States. The black carp, *Mylopharyngodon piceus* (Richardson 1846), was purposely introduced into the United States as a food fish and as a biological control agent for snails, an intermediate host for a trematode parasite of pond-cultured catfish. Although no known populations have established in the wild, there is great concern that if the black carp escapes captivity it will have major impacts on native mollusc and clam populations. In addition, it is host to a number of parasites and diseases that could be transferred to other fish species. The black carp is native to drainages of Eastern Asia (Figure 1A). GARP predictive modeling has indicated that if the black carp escapes, it has the potential to invade major portions of the United States and parts of Canada (Figure 1B). USACE facilities that lie within the darker areas are particularly susceptible to invasion and monitoring protocols should be implemented so that an invasion can be detected at an early stage and eradication procedures can be implemented.

Future Work

Site assessment modules will be developed for in-country aquatic invasive species and then for new introductions from overseas locations. Inclusion of analytical tools such as GARP offers the potential for predicting where on new landscapes invasions are most likely to occur. To further refine the site assessment modules, biotic and abiotic factors for each individual species can then be used to predict where a species is most likely to occur in a water body. Having this information available allows for the development of site-specific monitoring techniques, exclusion protocols, eradication methods, and management techniques in case they do establish.

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