GIS DECISION SUPPORT SYSTEM FOR PREVENTION OF BALLAST WATER-BORNE SPECIES INTRODUCTIONS

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ABSTRACT

Ballast water discharges are now known to be the single largest source of introduction of invasive marine species into new environments. Currently, no single comprehensive monitoring program provides the data necessary to produce an integrated assessment of the potential for ballast-water mediated species introductions into specific ports and/or coastal regions. Geographic Information Systems (GIS) is presented as a platform for integrating, processing and analyzing the various datasets involved in ballast water management. The result is a single comprehensive platform that links relevant trade, climatological, water quality and biological datasets to produce an integrated assessment tool for port-specific management of invasive species.

INTRODUCTION

The introduction of the Brown mussel (*Perna perna*) in 1990 (Hicks and Tunnell, 1993), and the Asian Green mussel (*Perna viridis*) in 1999 (Ingrao et al., 2001), demonstrated that Gulf of Mexico ports are not impervious to ballast-water borne species introductions. The total economic impact of invasive species on the U.S. economy is estimated at $137 billion annually (Pimental et al.., 2000). The potential impacts of such introductions into ports and more specifically, marine habitats cannot be over emphasized. Unlike other forms of pollution (e.g., oil spills) where ameliorative remedies allow eventually environmental recovery, species introductions are in most case irreversible, and once introduced nuisance species can cause major ecological and economic impacts in receiving environments.

THE PROBLEM

Ships pump ballast water on board to ensure stability and balance during transoceanic voyages. The need for ballast water varies with type of ship, cargo, and sea conditions. Aquatic organisms are often pumped into ballast tanks as ships take on seawater ballast. This water is released in varying amounts at or when ships approach ports to compensate for varying weight distributions as cargo is taken on and off (Carlton, 2001). Shipping moves over 80% of the world's commodities and transfers approximately 3 to 5 billion tonnes of ballast water internationally each year. In the United States alone, ballast water discharge rates were estimated at 2.4 million gallons per hour (Carlton, 1995). Several Gulf of Mexico ports are ranked among the top ten nationally in terms of receiving bulk carriers, which are subsequently the vessels responsible for the largest ballast water discharge volumes (Barrett-O'Leary et al., 1999). Hence the identification of ballast water as a major conveyor of introduced species.

The likelihood that specific ports or regions will be successfully invaded by nonindigenous species is dependent upon the complex interactions among several related factors including trade type and frequency, basic climatological factors, food resources, individual species' life histories, and the presence or absence of competitors, predators and parasites (Carlton 1996a, Barrett-O'Leary et al., 1999). Clearly, proactive strategies designed to prevent introductions will be most effective in the management of invasive species. High-risk sources of inbound ballast water can be identified by appropriate assembly of related environmental and biological data (Barrett-O'Leary et al., 1999). It has been shown that a port will be at greater risk of a ballast-mediated introduction if the physiochemical characteristics of its waters are similar to those of the donor's port (Smith et al., 1996). Integrated assessment tools, such as Geographic Information Systems (GIS), provide an effective platform for designing a database for assessing risk, developing risk reduction strategies and preparing (e.g. predicting impact and budgeting for control) for the possibility of introduction. This paper provides a model for the development of GIS-based, port-specific ballast water management using as an example, a system developed for the port of Corpus Christi, Texas. It also provides a system for assessing the potential for reciprocal transfers from specific ports to the waters of their trade partners.

DATABASE DESIGN AND DEVELOPMENT

A major challenge in ballast water management is attempting to extract information from the various relevant datasets (e.g., water quality, ship trade, climatological and biological) to create a tool that will be useful to port managers in the prevention of species introductions. Accordingly, ArcView 3.2 was used for database integration, analysis, and graphic display. A dataset containing biological and distributional information for more than 200 aquatic nuisance species (ANS) was constructed using Microsoft Excel and this was linked to the GIS database using an Avenue Script. The core GIS database consisted of the water quality, ship trade and climatological data. The follow gives an overview of the various datasets used.

1. Ship Trade Summary (STS) Data (1994 – 2000): compiled by the Port of Corpus Christi Authority (Carangelo, 2001). The data included:

A. Last port of call (LPOC) of all vessels loading cargo in the Port of Corpus Christi. These vessels were assumed to arrive at the Port of Corpus Christi "in-ballast" (no cargo, thus fully ballasted) with ballast water from the LPOC and therefore may potentially discharge ballast during cargo loading.

B. Ship destination / next port of call (NPOC) of all vessels unloading cargo in Port of Corpus Christi Authority System. These vessels were assumed to pick up ballast water in Corpus Christi and transport it to other destinations.

2. Water quality data (e.g., temperature, salinity, dissolved oxygen, chlorophyll content, etc. as available): the main source of water quality information utilized in the development of the database was from NOAA's National Oceanographic Data Centers (http://www.nodc.noaa.gov and http://www.ferret.noaa.gov). All data represented mean annual values.

3. Biological data: this database identifies more than 200 of the most notorious aquatic nuisance species and includes data related to their environmental limits, management information, potential impacts, and geographic distributions. These data are linked to various countries and their ports to allow identifications of known ANS harbored at the LPOCs.

DATA SCHEMA

The GIS database is organized in a nested fashion, from global to regional to local scales (e.g., see Figs. 1 – 3). At the global level, LPOC data are represented by FAO regions (standardized ocean regions used by the United Nations Food and Agriculture Organization, Fig. 1). The Last Port Of Call (LPOC) was assumed to be the origin of Ballast waters transported by vessels calling on the Port of Corpus Christi and subsequently discharged during cargo loading. A

High Frequency Trading Partner (HFTP) classification scheme was developed by applying the “natural breaks” grouping method in ArcView to Carangelo’s (2001) LPOC loadings dataset, resulting in classes of similar values separated by breakpoints. Optimal class divisions were determined via Jenks' optimization method. In this method, the optimal partition for each subset is the one with the smallest total error (the sum of absolute deviations about the class median, or alternatively, the sum of squared deviations about the class mean). The data was normalized to percentage and categorized into the following classes in ArcView:
Very low (0 - 0.001); Low (0.001 - 0.004); Average (0.004 - 0.012); High (0.012 - 0.155); and Very high (0.155 - 0.763).

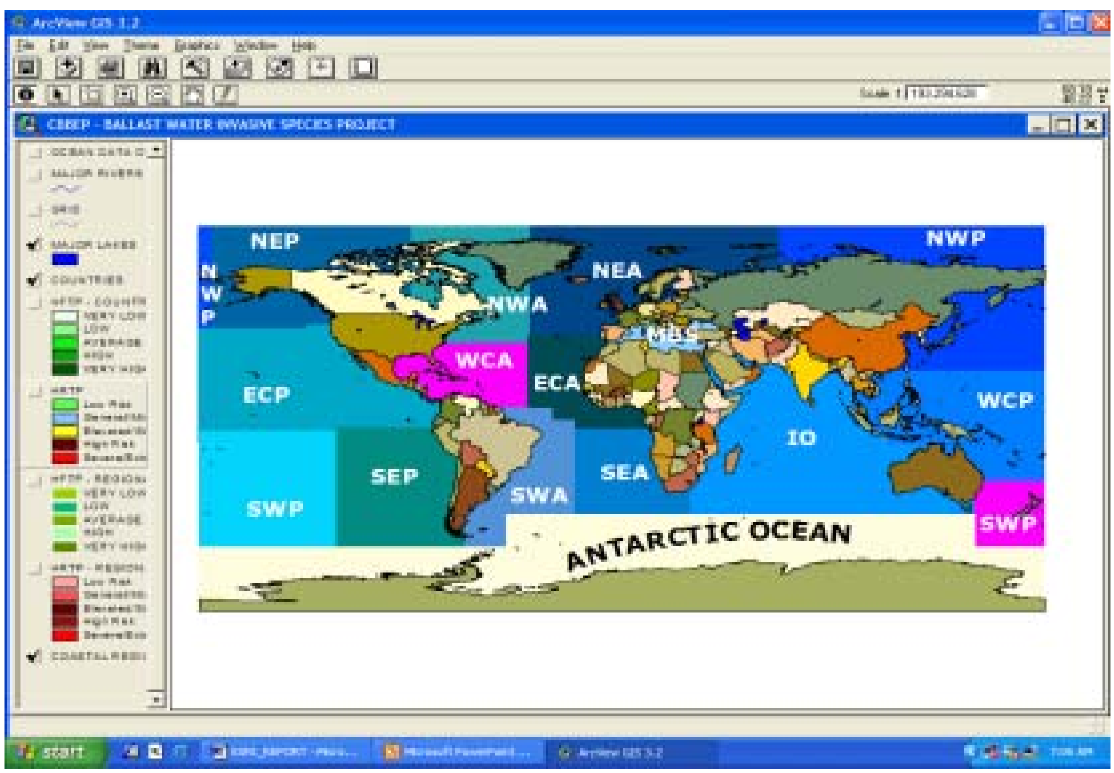

Fig. 1 Global view interface depicting FAO regions

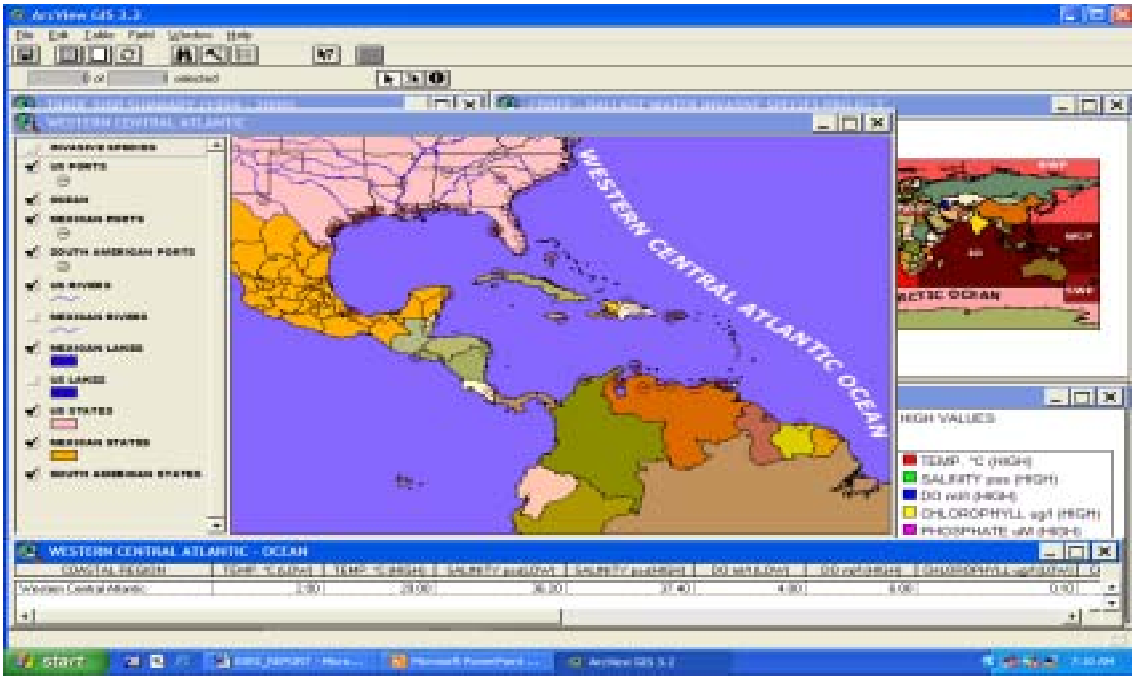

Fig. 2. Detailed link to a particular region showing an overview of environmental data

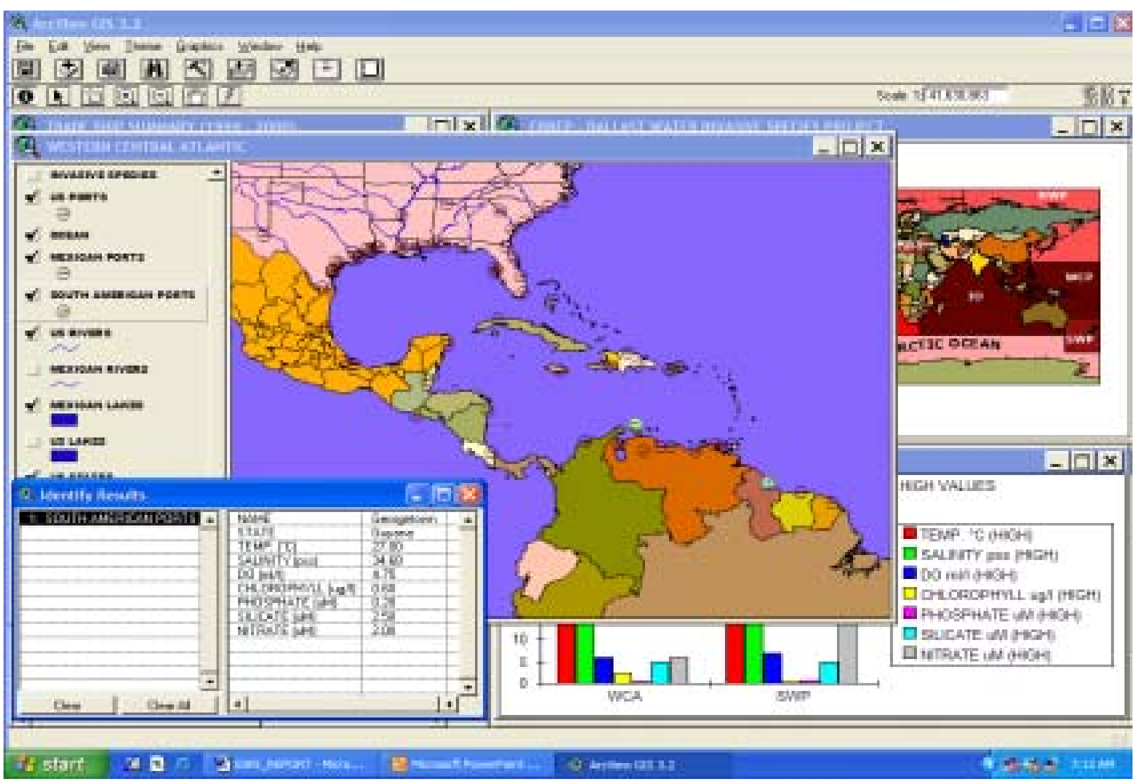

Fig 3. Link to a particular port showing its attribute information

A High Risk Trading Partner (HRTP) classification scheme was developed from the two main datasets: the HFTP classification (particularly the ship trade summary for each country) and the environmental dataset compiled for each country. For this classification, the HFTP (see fig. 4) groupings were reassigned the following values: Very low = 1, Low = 2, Average = 3, High = 4, and Very high = 5. A similar ranking scheme was applied to the environmental/climatic data set. Geographic areas having environmental/climatic characters similar to the Western Central Atlantic (WCA) FAO region (Port of Corpus Christi) were given a value of 5 and values <5 indicating a decreasing order of similarity. The High Risk Trading Partner (HRTP) classification (see fig. 5) was then constructed using the following formula: $a(X1-1) + b(X2-1)$, where X1 is the HFTP value (1-5 value), X2 is the climatic similarity value (1-5 value), $a = 1$, and $b = 10$. Accordingly, each HFTP-climatic similarity combination is assigned a unique value and the climatic data is weighted. In the formula, subtracting 1 from each of the category values indicates that values greater than 1 add to the risk in each category. Breakpoints in the range of generated HRTP values were estimated via Jenks' optimization method. The resulting five groups were reassigned HRTP Risk Factor values ranging from 1 – 5: Low risk = 1, General/minimal risk = 2, Elevated/significant risk = 3, High risk = 4 and Severe risk = 5. Accordingly, high frequency trading partners originating from domestic ports would have a highest risk of introducing nuisance species.

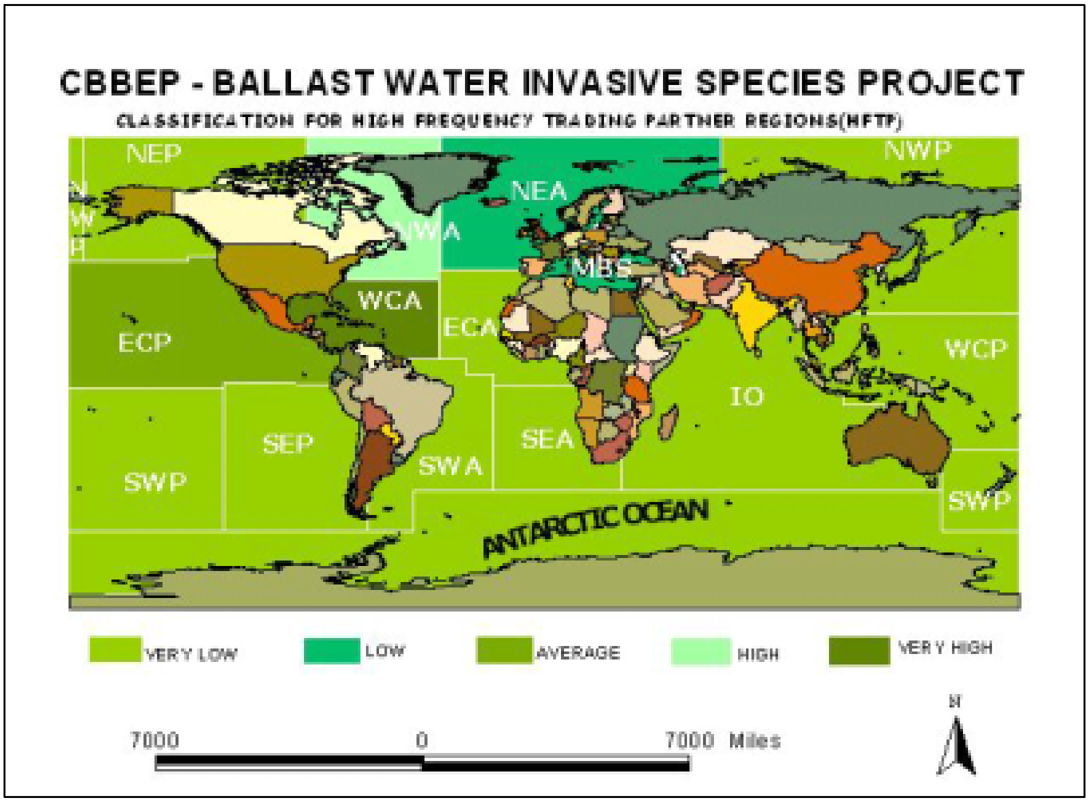

Fig. 4 Classification for High Frequency Trading Partners (HFTP)

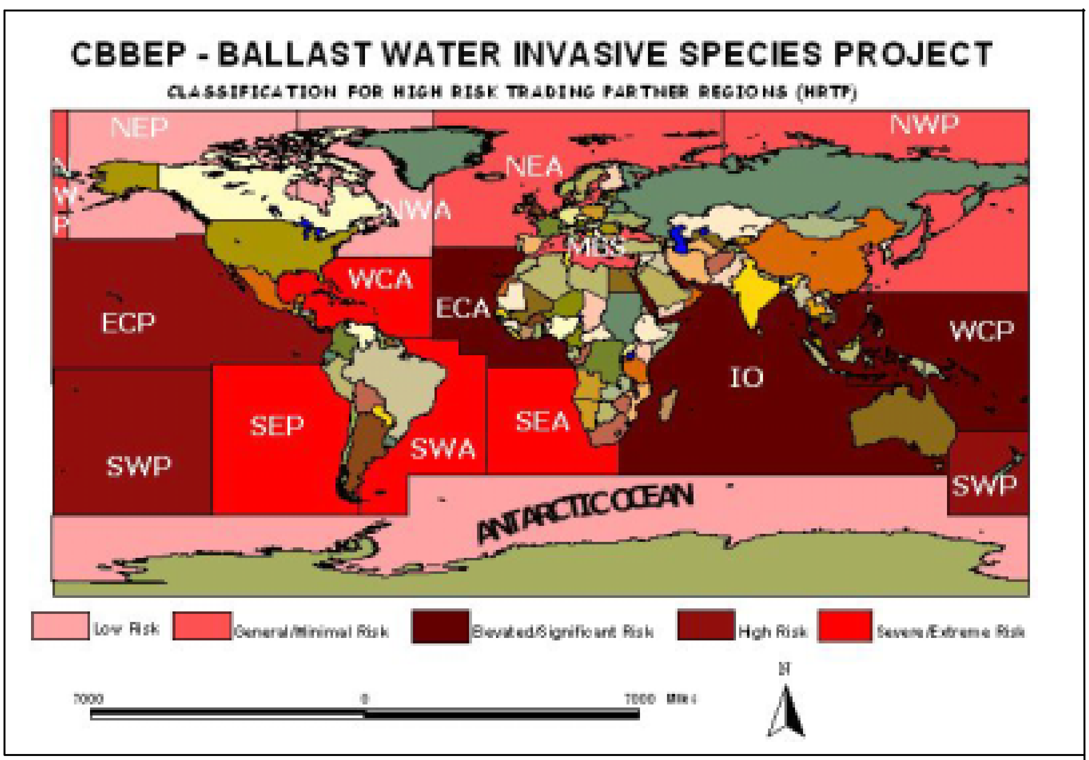

Fig. 5 Classification for High Risk Trading Partners (HRTP)

RESULTS AND CONCLUSIONS

This GIS database allows users to address a variety of issues related to ballast water-mediated invasive species risk assessment. For example, database queries such as “find all HFTP ports in the Western Central Pacific” and “find all states where the Zebra mussel has invaded” can readily be accessed. Additionally, this GIS database has the capacity to integrate information across the various data sets (LPOC frequencies, environmental characters, and invasive species). For example, it can generate maps highlighting ports having source waters falling within a particular range of temperature and salinity values. In addition, the database can generate lists of known exotic species inhabiting areas grouped by HRTP categories. The addition of ship destination data (next port of call), allows for the assessment of potential reciprocal transfers from Corpus Christi Bay waters to the waters of its trade partners.

In our example for the Port of Corpus Christi, information relating to 464 individual ports (LPOCs) representing 15 FAO regions was included in the database. Of these, 110 were considered Severe/extreme risk, 24 High risk, 101 Elevated/significant risk, 185 General/minimal risk, and 44 Low risk based upon the HRTP criterion (see above). Ports classified as Severe Risk are located in regions from which a total of 22 aquatic invertebrates, 9 aquatic plants, 1 aquatic vertebrates and 1 pathogen have been documented as successful invaders. High risk ports are located in regions from which 55 aquatic invertebrates, 14 aquatic plants, and 2 aquatic vertebrates have been introduced. Elevated/significant risk ports are located in regions from which a total of 26 aquatic invertebrates, 9 aquatic plants, and 2 aquatic vertebrates have been introduced.

The current limitation is in the use of LPOC as the sole predictor of ballast water origin. LPOC is most accurate in identifying origin of ballast waters for ships with very direct routes, and may not be representative of the actual ballast water being transported by ships calling on multiple ports (Barrett-O’Leary et al., 1999). In fact, Smith et al. (1996) found that 53% of vessels did not contain ballast waters from the LPOC. Further, the accuracy of LPOC data in identifying ballast origin decreases with increasing vessel size (i.e., container ships vs. tankers). Unfortunately, record keeping and is not required beyond the LPOC. The inclusion of such data (e.g., the previous ten ports-of-call) would greatly facilitate ballast-mediated risk assessment.

The port-ballast water risk assessment GIS approach is an integrated methodology which can be utilized to develop ballast water management policies specific to individual ports and/or regions. Risk assessment summaries from various analyses can be made and alternate outcomes projected, debated and revised so that informed decisions could be made.

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LITERATURE CITED

Barrett O'Leary, M., C. Popov, and Y. Allen. 1999. Assessing the potential for introduction of nonindigenous species through U.S. Gulf of Mexico ports. Louisiana Sea Grant College Program, Louisiana State University.

Carangelo, P.D. 2001. Data Report and Assessment Concerning Potential Ballast Introduction into the Port of Corpus Christi, Texas. Data compilation, Screening, Determination of Potential Source and Volume of Ballast Water, and Comparison of Existing Project Future Conditions and Proposed Corpus Christi ship Channel Improvement Project Future Conditions. Port of Corpus Christi Authority.

Carlton, J.T. 1996a. Pattern, process, and prediction in marine invasive ecology. Biological Conservation 78: 97-106. Carlton, J.T. 2001. Introduced species in U.S. coastal waters: environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia.

Carlton, J.T., D.M. Reid and H. van Leeuwen. 1995. Shipping Study – The role of shipping in the introduction of non-indigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options. U.S. Coast Guard, Report No. CG-D-11-95.

Hicks, D.W. and J.W. Tunnell. 1993. Invasion of the south Texas coast by the edible brown mussel Perna perna (Linnaeus, 1758). The Veliger 36(1): 92-94.

Ingrao, D.A., P. Mikkelsen, and D.W. Hicks. 2001. Another introduced marine mollusk in the Gulf of Mexico: the Indo-Pacific green mussel, Perna viridis in Tampa Bay, Florida. Journal of Shellfish Research 20(1): 13-19.

U.S. Environmental Protection agency (EPA). September 2001. National Coastal Condition Report. EPA - 6201R-01/005.

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