# Assessing the Risk of Introducing Exotic Species via the Live Marine Species Trade

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**Abstract:** *Although the shipping industry has received considerable attention as a dispersal mechanism for aquatic nuisance species, many invasions have been linked to other mechanisms of transfer. The threat posed to coastal ecosystems by these alternative mechanisms, however, remains largely unquantified. We assessed the potential risks of introducing marine and estuarine species associated with seven mechanisms of transfer: seafood companies, aquaculture operations, bait shops, stores that sell marine ornamental species, research and educational organizations, public aquariums, and coastal restoration projects. For each, we compiled a comprehensive database of organizations in coastal Massachusetts. We then designed and administered a survey to a subset of organizations that inquired about (1) their proximity to saltwater and methods of handling live imports; (2) the type and quantity of marine species being imported; and (3) the organization's familiarity with marine invasions. Respondents in five of the seven categories acknowledged importing nonlocal live marine species to the area. Seafood companies handled the majority of individuals but relatively few taxa. This mechanism of transfer also had the most complex trade patterns and the greatest number of operations located near saltwater. In contrast, the other transfer mechanisms each had simpler trade pathways and fewer operations but varied in the quantity and taxonomic diversity of their imports. Significantly, no single mechanism of transfer stood out as presenting a primary risk. Rather, each had characteristics or used handling practices at different points in the importation process that could facilitate introductions. To prevent future marine invasions, better reporting requirements for live species imports are needed, and best-management practices and outreach strategies specific to the transfer mechanism should be developed and implemented.*

**Key Words:** estuarine species, prevention of invasive species, risk of invasions, species introductions, transfer mechanisms of invasive species

Evaluación del Riesgo de Introducciones de Especies Exóticas a través del Comercio de Especies Marinas Vivas

**Resumen:** *Aunque la industria de transportación marítima ha recibido considerable atención como un mecanismo de dispersión de especies acuáticas molestas, muchas invasiones han sido relacionadas con otros mecanismos de transferencia. Sin embargo, la amenaza de estos mecanismos alternativos a los ecosistemas costeros permanece en gran parte sin cuantificar. Evaluamos los potenciales riesgos para especies marinas y estuarinas asociados con siete mecanismos de transferencia: compañías de mariscos, operaciones acuaculturales, tiendas de especies marinas ornamentales, organizaciones de investigación y educativas, acuarios públicos y proyectos de restauración costera. Para cada uno, compilamos una amplia base de datos de organizaciones en la costa de Massachussetts. Luego diseñamos y aplicamos una encuesta a un subconjunto de organizaciones para obtener información sobre (1) su proximidad al agua marina y sus métodos para el*

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*manejo de importaciones vivas, (2) el tipo y cantidad de especies marinas importadas y (3) la familiaridad de la organización con invasiones marinas. Evaluamos los potenciales riesgos de introducciones de especies marinas y estuarinas. Los encuestados en cinco de siete categorías reconocieron importar especies marinas vivas no locales al área. Las compañías de mariscos manejaron a la mayoría de los individuos pero relativamente pocos taxa. Este mecanismo de transferencia también tuvo los patrones comerciales más complejos y el mayor número de operaciones localizadas cerca de agua marina. En contraste, cada uno de los demás mecanismos de transferencia tuvo canales de comercialización más simples y menos operaciones, pero variaron en la cantidad y diversidad taxonómica de sus importaciones. Significativamente, ningún mecanismo individual resaltó como un riesgo primario. Más bien, cada uno tenía características o utilizaba prácticas de manejo en diferentes etapas del proceso de importación que podían facilitar las introducciones. Para prevenir futuras invasiones marinas, se necesitan mejores requerimientos para reportar la importación de especies vivas, y se deben desarrollar e implementar prácticas de manejo óptimo y estrategias de extensión específicas para el mecanismo de transferencia.*

**Palabras Clave:** especies estuarinas, introducción de especies, mecanismos de transferencia de especies invasoras, prevención de especies invasoras, riesgo de invasiones

## Introduction

Introductions of harmful marine organisms are a source of considerable concern. Since the arrival of the first European settlers, at least 400 exotic marine and estuarine species have become established in North America (Ruiz et al. 1997) and a subset of these has caused significant economic and ecological damage (e.g., Ropes 1968; Kimmerer et al. 1994). These deleterious impacts are particularly alarming because (1) the rates of introduction in aquatic systems are increasing (Mills et al. 1993; Cohen & Carlton 1998; Ruiz et al. 2000); (2) we are still unable to predict when or where an invasion will occur (Carlton 1996; Mack et al. 2000); and (3) controlling an invasion once it has become established and widespread can be expensive and difficult (Office of Technology Assessment 1993; Pimentel et al. 2000) and in the marine environment is usually impossible. As a consequence, the best strategy for minimizing damage from invasive species is to prevent their release into the environment. To accomplish this, we must identify the principal mechanisms that move exotic species to a region and determine the specific risks associated with importation and handling by each mechanism.

### Mechanisms for Transporting Marine Invaders

Ballast-water transport and hull-fouling transfers by commercial ships are primary mechanisms for aquatic introductions (Ruiz et al. 2000). Studies assessing invasion potential via ballast water have quantified the volume and frequency of water being released (Lavoie et al. 1999; Wonham et al. 2000), the abundance and variety of species found in the ballast water (Carlton & Geller 1993; Smith et al. 1999), survivorship during transport (Smith et al. 2001; Wonham et al. 2001), and environmental characteristics of the receiving region (Smith et al. 1999). In contrast, most information on nonshipping mechanisms has been largely anecdotal or qualitative (Courtney & Williams 1992; Elston 1997), even though many characteristics of nonshipping mechanisms are quantifiable (e.g., fate of the holding-tank water, the quantity of species imported). Ultimately, such information is necessary if we are to compare the relative risk of shipping versus nonshipping mechanisms and encourage cost-effective management strategies for each.

Nonshipping mechanisms for the introduction of marine species include commercial enterprises, such as aquaculture, seafood, bait, and aquarium industries; research and educational organizations, such as colleges, universities, and public aquariums; and private or government activities, such as coastal restoration and fishery stock enhancement (Carlton 1992). Among commercial enterprises, the aquaculture and seafood industries have played substantial roles in marine biological invasions, particularly with regard to the transport of shellfish. For example, the virus *Bonamia ostreae* accompanied shipments of the European oyster (*Ostrea edulis*) from Washington State to France in 1979 and subsequently decimated native French oyster stocks (Farley 1992). In the last decade, the Chinese mitten crab (*Eriocheir sinensis*) has become a major nuisance in the San Francisco estuary. Its high market value, coupled with frequent interception as living animals in baggage originating from Asia, suggest that the crab may have been intentionally introduced (Cohen & Carlton 1997).

The bait and marine ornamental species industries and educational organizations have also been linked to aquatic invasions. Both the green crab (*Carcinus maenas*) and the alga *Codium fragile* (Suringar) Hariot spp. *tomentosoides* (van Goor) Silva were likely transported to the West Coast of the United States in seaweed used to pack shipments of bait worms (Lau 1995). Numerous aquatic flora and fauna, farmed for the aquatic ornamentals industry, have invaded the waters of the southeastern United States (Courtenay & Williams 1992). A public aquarium in Monaco introduced the Australian seaweed *Caulerpa taxifolia* (Vahl) C. Agardh into the Mediterranean Sea in

1984, and the alga now carpets large expanses of the sea bottom in the western Mediterranean (Wiedenmann et al. 2001).

Finally, privately or publicly funded coastal wetland restoration projects may represent another important mechanism for marine invasions. Historically, landscapers and restorers have selected plants for ornamental and functional reasons (Newcomb 1989), and the geographic origins of the plants have been of little concern. Many nurseries now sell coastal plants specifically for restoration purposes and advertise shipment to anywhere in the United States.

Though contributions of various nonshipping mechanisms of transfer to the introduction of exotic species have been investigated over historical time scales for certain regions (Mills et al. 1993; Ruiz et al. 2000), comparative studies of currently active mechanisms are lacking. We assessed the risk associated with the movement of live marine organisms to a given locale by multiple nonshipping mechanisms. We were expressly interested in imported live non-native organisms because these species and their parasites, diseases, biological packing material, and associated hitchhiking species have the potential to survive and reproduce in and invade a new community (Naylor et al. 2001; Stickney 2002; Chapman et al. 2003).

### A Comparative Study of Nonshipping Mechanisms of Transfer

The eastern portion of Massachusetts is a major commercial, recreational, and educational hub in New England. Many marine-based businesses are found along its coastline, including seafood companies, aquaculture operations, and bait shops. Massachusetts is also home to many marine-life enthusiasts, who support local aquarium shops and public aquariums, and to educational institutions that study marine organisms. Over 50 exotic species have been found in the Gulf of Maine (Steneck & Carlton 2001), many of which have arrived in the last several decades. Because Boston and other New England ports receive relatively little ballast water (Smith et al. 1999), alternative pathways for exotic marine introductions may be important in this region.

The risk of a successful introduction is likely to increase if a dispersal mechanism provides repeated opportunities for the introduction of exotic species or their gametes into the local environment (Ruesink et al. 1995; Ruiz et al. 2000), transports exotic species capable of surviving in the local environment (Tucker & Richardson 1995; Smith et al. 1999), and includes sufficient numbers of the exotic species to sustain a population (Mack et al. 2000). To determine whether trade in live marine species in Massachusetts met any of these criteria, we determined the number of entities and the links between components in each respondent group and designed and administered a survey to a subset of each group which inquired about (1) the on-site practices each organization used when handling live marine organisms and (2) the type, quantity, and geographic origin of marine organisms being imported. We also asked about the respondents' familiarity with the topic of marine invasive species because their efforts to prevent release might depend on recognition that a potential hazard exists. We compared the survey data to determine whether certain aspects of the importation process in each group or particular dispersal mechanisms as a whole posed greater risks than others. Theoretically, an unwanted introduction could be prevented if the higher-risk features were identified and controlled. Therefore, we paid close attention to instances where management practices could be developed and implemented to curb these risks.

## Methods

### Database Compilation

We used local trade directories (e.g., 1999–2000 Bell Atlantic Yellow Pages, 1999–2000 American Business Directory) and government resources (e.g., the U.S. Food and Drug Administration's Interstate Shellfish Shippers List) to compile a list of organizations in the coastal region of Massachusetts that were likely to work with live marine or estuarine (henceforth referred to as marine) species. Most organizations were within 160 km of the coastline, and we used telephone area codes (617, 781, 508) to delineate our boundaries. The database consisted of commercial enterprises, marine research and educational organizations (henceforth referred to as research), public aquariums, and coastal restoration projects completed or underway in Massachusetts. Within our geographic boundaries, the marine ornamentals industry consisted almost entirely of retail stores (versus wholesalers) that sell marine fish, invertebrates, and plants to aquarium hobbyists. We distinguished research organizations from public aquariums because they differ in important ways, such as the number and volume of imported species and the level of institutional oversight. For each dispersal mechanism, we determined the number of product exchange points along the trade route, approximated the number of importers in the region, and generated a list of survey candidates.

In a preliminary screening of the database, we reduced the number of entities surveyed based on several criteria. First, we excluded importers that fell outside our geographic range. Second, some individuals or organizations did not work with live marine species and so were also excluded. Third, with the exception of marine researchers, we excluded individuals such as marine aquarium hobbyists, seafood customers, and recreational fishers from the study for logistical reasons. We surveyed individual researchers, rather than their institutions, because we assumed that each researcher worked independently. Fourth, the seafood industry had a greater number of product-exchange points than the other industries. Site visits and telephone calls also revealed that many of the

seafood retail stores were solely engaged in selling local products to local customers. For these reasons, the number of seafood companies included only wholesalers. Retail stores that engaged in both retail and wholesale trade remained in the database.

### Survey Design

We developed a general survey to compare characteristics and handling practices among organizations. The survey consisted of approximately 30 questions divided into four sections (Weigle 2002). The first section included questions about the facility and the company (e.g., proximity of company to nearest body of water, means of disposing of tank holding water). The second and third sections consisted of questions and charts designed to collect data on the variety and volume of live marine species being imported and exported (not reported here), respectively, and the associated handling practices en route. The fourth section inquired about the respondent's familiarity with and interest in the topic of marine bioinvasions. Where possible, we avoided open-ended questions (Salant & Dillman 1994). Industry councils and representatives from each type of mechanism of transfer reviewed and edited the surveys, and surveys were modified to incorporate language and questions appropriate to the type of mechanism being surveyed. For example, we asked respondents from seafood and bait companies about the importation and handling of live and "fresh" (i.e., dead and chilled) products. We considered that fresh products pose a risk of species introductions because some parasites, disease-causing organisms, and hitchhiking species can survive chilling. Respondents from other transfer mechanisms did not handle fresh products, so their survey questions dealt only with live imports.

For all surveys, we defined *local* as the coastal states of New England (Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut) and their associated water bodies, ranging from northern Maine to the northern portion of Long Island Sound. We use the term *nonlocal* to describe regions outside the coastal states of New England. We used this terminology to minimize confusion on the part of the respondents between what was native versus non-native. On occasion, however, local species could include established non-native species (e.g., the European oyster [*Ostrea edulis*]). Likewise, in a few instances, nonlocal species included imported species that were indigenous to New England waters (e.g., lobster [*Homarus americanus*] from Canada). We avoided judgmental language in distinguishing between local and nonlocal species, even though the focus of our study was nonlocal live or fresh marine imports.

### Secondary Screening and Survey Distribution

Prior to general distribution, we conducted a pilot survey of a randomly selected subset of organizations from each type of dispersal mechanism. The pilot survey demonstrated that there were still a significant number of entities that worked only with local species. Thus, we conducted a second screening in which we contacted a subset of entities in each category by telephone or email and asked whether they imported nonlocal live marine plants or animals to Massachusetts. We were unable to reach the aquaculture industry during this time. Following the second screening, we distributed surveys between October 2000 and May 2001 to the candidates and to a randomly selected group of unreachable organizations. We did not distribute surveys to restoration organizations. Instead, we interviewed several government scientists, private consultants and contractors, and workers at saltwater nurseries by telephone.

### Data Analysis

We used JMP 4.0.4 (SAS Institute 2000) to perform the statistical analyses. We did not include public aquariums in any statistical analyses because they were few in number. We used two-way contingency tables to test response frequencies (e.g., number of respondents importing versus not importing live marine organisms) for independence among dispersal mechanisms. For each categorical question, we calculated percentages by dividing the number of responses to a given category of a question by the total number of respondents answering all categories of the question. We tabulated responses from the written survey only for those respondents who imported nonlocal live or fresh marine species.

We calculated the total number of nonlocal live or fresh marine taxa imported by each transfer mechanism by summing the number of different taxa reported. In instances where species names were not provided, we pooled organisms into the lowest distinguishable taxonomic grouping (e.g., clams were listed as one taxon even though more than one species may have existed). Most participants reported the quantity of imported organisms as individual counts. Seafood companies reported their imports by weight. For consistency, we converted seafood weights to approximate numbers of individuals. We calculated the total number of organisms imported annually by each dispersal mechanism by multiplying the average number of organisms reported in the surveys by the potential number of importers in each mechanism.

## Results

### Number of Importers and Importation Complexity

Five of the seven organizational types we surveyed imported nonlocal live or fresh marine species. For the seafood, bait, and marine ornamentals industries, both retailers and wholesalers handled nonlocal product. In the

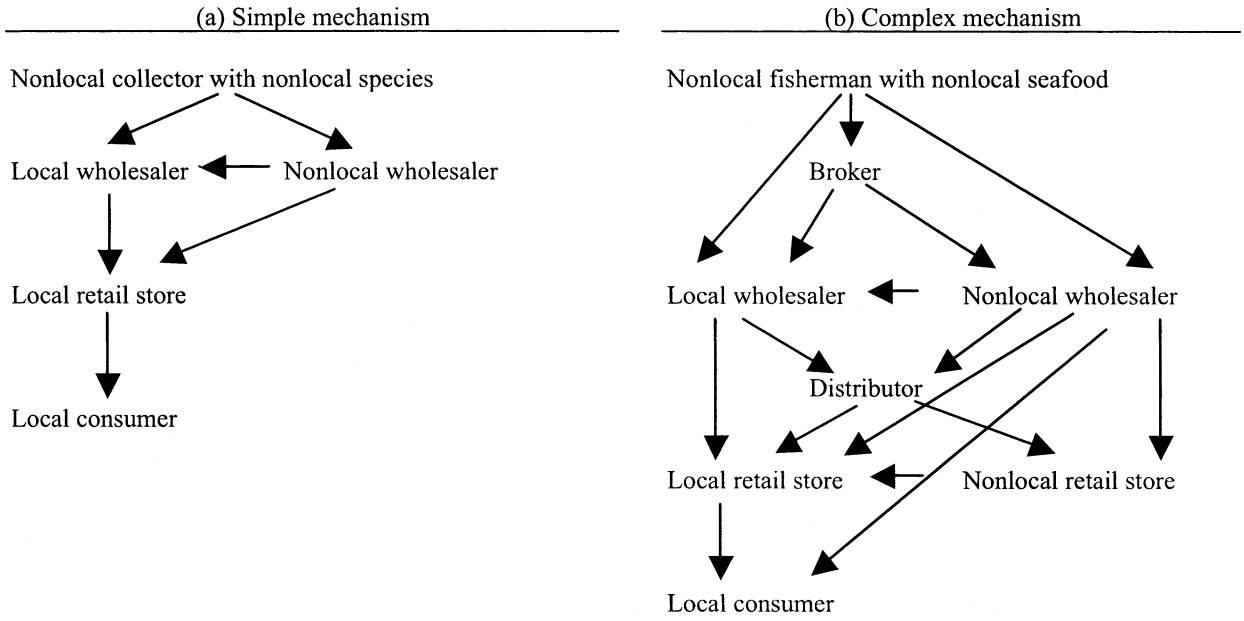


*Figure 1. Comparison of constituents and exchange points in (a) a simple mechanism of transfer of marine organisms, such as bait or marine ornamentals industries versus (b) a complex mechanism of transfer, such as the seafood industry.*

research category, universities, colleges, private research institutions, and biological research suppliers acknowledged importing live marine organisms. In contrast, medical and veterinary schools, hospitals, and biotechnology companies did not. Neither the aquaculture industry nor coastal restoration projects reported bringing nonlocal marine species into Massachusetts.

Some importation pathways were simple. For example, the bait and marine ornamentals industries involved only four levels of exchange and a total of six links between the collector and consumer (Fig. 1a). Each constituent in these industries had a clearly defined role in the exchange. The research and public aquarium organizations were also straightforward. Researchers usually bought nonlocal marine species from out-of-state marine biological suppliers. Public aquariums either collected their own nonlocal specimens or obtained them via aquarium trade programs. In contrast, the seafood industry had six possible levels of exchange with 16 different links between source and end point (Fig. 1b). Seafood companies often played multiple roles in the transfer of products.

Initial examination of trade directories and government lists yielded over 1900 entities in coastal Massachusetts that potentially handled live marine organisms (prescreen number, Table 1). Our preliminary screening criteria reduced the total number of entities to 1382 (modified number, Table 1). In the second screening (i.e., telephone calls and emails to a subset of the modified number), we contacted a sufficient percentage of the entities ($\leq$6% sampling error at 95% confidence interval; Weigle 2002) importing live or fresh nonlocal marine species to estimate characteristics for the entire population for each mechanism. The proportion of entities importing live or fresh nonlocal marine species differed significantly among dispersal mechanisms (two-way contingency table; $\chi^2 = 68.2$; df = 3,457; $p < 0.0001$; column 6, Table 1). For example, only 18% of the bait industry and 35% of researchers imported live or fresh nonlocal marine species. In contrast, most of the businesses that sold aquatic ornamental species and all public aquariums imported nonlocal marine species. In total, 399 entities in coastal Massachusetts imported live or fresh nonlocal marine species (potential number, Table 1). Despite exclusion of retailers, the seafood industry comprised 55% (219) of the total number of potential importers.

### Survey Responses

Of the 499 surveys distributed, 159 (32%) were completed and returned (Table 1). From 29% (seafood) to 100% (public aquariums) of the organizations within a group were surveyed (Table 1). We could not estimate the number of aquaculture operations or restoration projects. Hereafter, data are summarized only for those survey respondents that indicated they imported nonlocal live or fresh marine species.

### Opportunities for Release

The proportion of facilities within 150 m of the nearest body of saltwater differed significantly among dispersal mechanisms (two-way contingency table; $\chi^2 = 24.6$; df = 3, 88; $p < 0.0001$) (Fig. 2a). Most of the researchers and all the public aquarium respondents were located next to a water body. In contrast, the majority of seafood, bait,

**Table 1. Estimated number of entities in each type of nonshipping mechanism of transfer of marine organisms following preliminary and secondary screenings (na, not available).**

| *Mechanism* | *Prescreen number*[a] | *Modified number*[b] | *Entities contacted*[c] | *Handle live marine species*[d] | *Import nonlocal species* | | | *Total surveys distributed*[b] | *Total surveys returned*[i] | *Potential number surveyed (%)*[j] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *positive respondents*[e] | *%*[f] | *potential number*[g] | | | |
| Seafood | 831 | 524 | 160 | 114 | 67 | 42 | 219 | 242 | 64 | 29 |
| Aquaculture | 333 | 289 | na | na | na | na | na | 41 | 20 | na |
| Bait | 243 | 210 | 126 | 68 | 23 | 18 | 38 | 58 | 21 | 55 |
| Ornamentals | 212 | 86 | 62 | 49 | 49 | 79 | 68 | 39 | 20 | 29 |
| Research | 240 | 203 | 115 | 85 | 40 | 35 | 71 | 116 | 31 | 44 |
| Public aquarium | 3 | 3 | 3 | 3 | 3 | 100 | 3 | 3 | 3 | 100 |
| Restoration | 67 | 67 | na | na | na | na | na | na | na | na |
| Total | 1929 | 1382 | 466 | 319 | 182 | 39 | 399 | 499 | 159 | 40 |

[a] *Prescreen number of entities (businesses, individuals, organizations) based on trade and government listings.*
[b] *Modified number of entities following preliminary screen (see Methods). For restoration,* n *is the number of coastal restoration projects completed or underway in Massachusetts.*
[c] *Number of entities in modified number contacted during secondary screening by telephone or email.*
[d] *Number of entities contacted that worked with live or fresh (i.e., dead and chilled; not frozen, salted, or canned) marine species.*
[e] *Number of entities contacted that imported live or fresh marine species from nonlocal regions (i.e., outside New England).*
[f] *Percentage of entities contacted that imported live or fresh marine species from nonlocal regions: (column 5/column 3) × 100.*
[g] *Potential number of entities per mechanism in eastern Massachusetts importing live or fresh nonlocal marine species: column 6 × column 2.*
[b] *Total number of surveys distributed.*
[i] *Total number of surveys completed and returned.*
[j] *Percentage of potential number of entities surveyed: (column 9/column 7) × 100.*

and aquatic ornamentals businesses were situated farther than 150 m from a water body. Because the seafood industry was so large, it had the greatest absolute number of operations located beside a saltwater body.

Respondents in all groups reported that they discharged tank water used to hold nonlocal species directly into a local water body rather than through a municipal drainage line (Fig. 2b). The aquatic ornamentals stores and public aquarium respondents treated or filtered the tank water before releasing it. In contrast, among the seafood, bait, and research organizations, more than half of those discharging tank water directly into the waterway did so without treatment or filtration (Fig. 2b, open bars). In another example of a direct release, seafood businesses sometimes disposed of product by selling it to local fishers to use as bait. The seafood industry was the only type of transfer mechanism in which delivery trucks containing imported live species were washed down on site within close proximity to a water body.

### Taxonomic Variety and Volume

The variety of taxa imported differed significantly among industries (Kruskal-Wallis test; $\chi^2 = 32.9$; df = 3; $p < 0.0001$). Both marine ornamentals stores and public aquariums reported cumulative imports of hundreds of taxa (Fig. 3a), whereas seafood, bait, and research respondents imported relatively few (6–32) taxa. None of the seafood and bait respondents, however, used species names to describe imports, so these figures are conservative estimates. Researchers imported a variety of invertebrates, vertebrates, and algae. In contrast, seafood, bait, marine ornamentals, and public aquarium respondents imported mostly fish species. Stores that sold marine ornamentals received over 95% of their marine species from tropical regions, whereas all bait came from temperate regions. Respondents in the remaining transfer mechanisms brought in species from both tropical and temperate regions.

The number of individual organisms imported differed significantly among the types of respondents (Kruskal-Wallis test; $\chi^2 = 27.8$; df = 3; $p < 0.0001$) and spanned several orders of magnitude (Fig. 3b). Seafood companies brought in more live and fresh organisms annually to Massachusetts than the other four types of transfer mechanisms combined. Molluscs and lobsters dominated live seafood imports numerically (Weigle 2002). Many of these shellfish species came from eastern Canada or the mid-Atlantic coast of the United States and were indigenous to Massachusetts waters. Finfish species were also a major import of seafood companies, but they were brought in as fresh rather than live product.

Imported species often arrived packed in seaweed or seawater and were accompanied by hitchhiking (i.e., nontarget) organisms. For example, 60% of bait-business respondents who imported nonlocal product reported that they received bait packed in seaweed, and 80% of the marine ornamentals respondents received imported organisms in seawater (Fig. 4a). A high percentage of survey respondents in all categories observed nontarget species (e.g., crustaceans, molluscs, worms) associated with the imported nonlocal species (Fig. 4b).

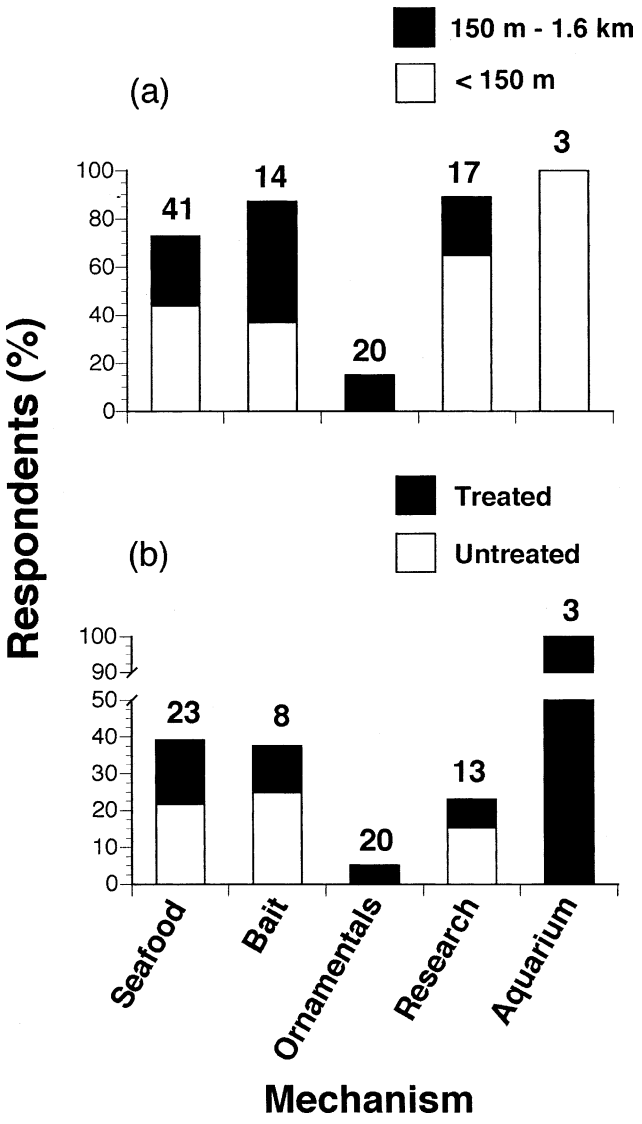


*Figure 2. Percentage of respondents importing nonlocal live or fresh marine organisms that (a) were located within 1.6 km of a body of water or (b) discharged holding-tank water directly into the local water body. "Treated" means that discharged water is treated or filtered prior to release. Total number of survey respondents per transfer mechanisms is reported above each bar. In (b) total number includes only respondents who held marine organisms in water tanks.*

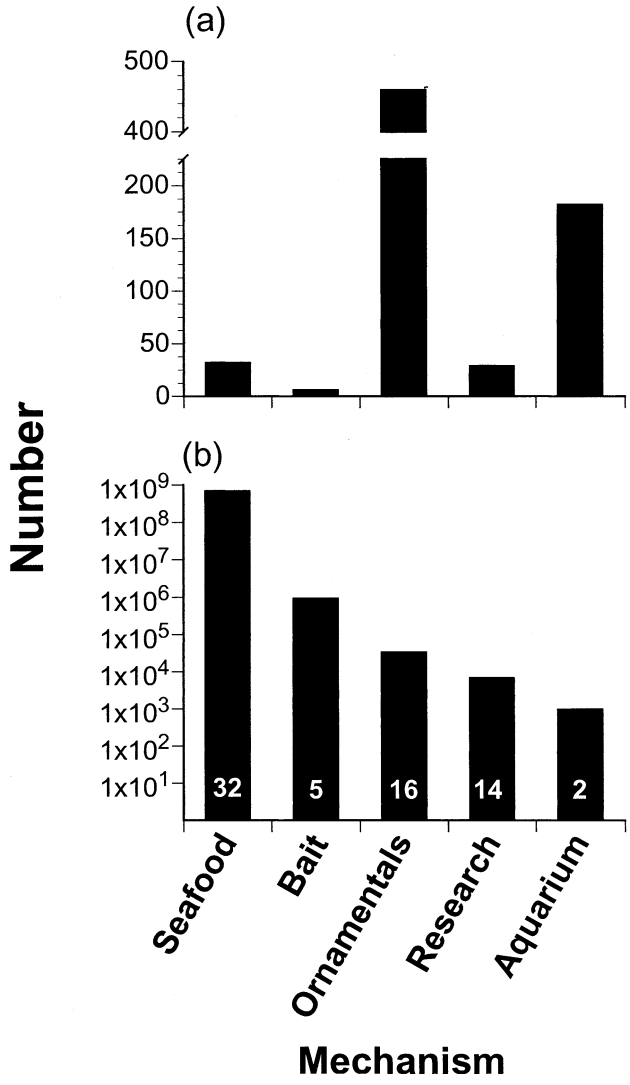


*Figure 3. (a) Number of nonlocal live or fresh marine taxa and (b) number of individual nonlocal organisms imported by mechanism of transfer. Number of survey respondents per mechanism type is reported inside each bar. In (b) the number of individuals imported is extrapolated to the potential number of entities (column 7, Table 1) in each mechanism of transfer.*

### Interest and Awareness

Respondents differed significantly in their familiarity with the topic of marine invasions (two-way contingency table; $\chi^2 = 16.2$; df = 3, 79; $p = 0.0010$). A substantial number of the total respondents in the seafood (20 of 34), bait (6 of 13), and marine ornamentals (6 of 19) industries were not familiar with the phenomenon. In contrast, most researchers (15 of 16) and all public aquarium respondents were familiar with marine invasions. At least two-thirds of the respondents in each transfer mechanism expressed an interest in learning more.

## Discussion

### Trade-Related Risks

Introductions of nonindigenous species in aquatic and terrestrial systems are frequently associated with trade (Carlton 1992; Mack et al. 2000). Our results showed that

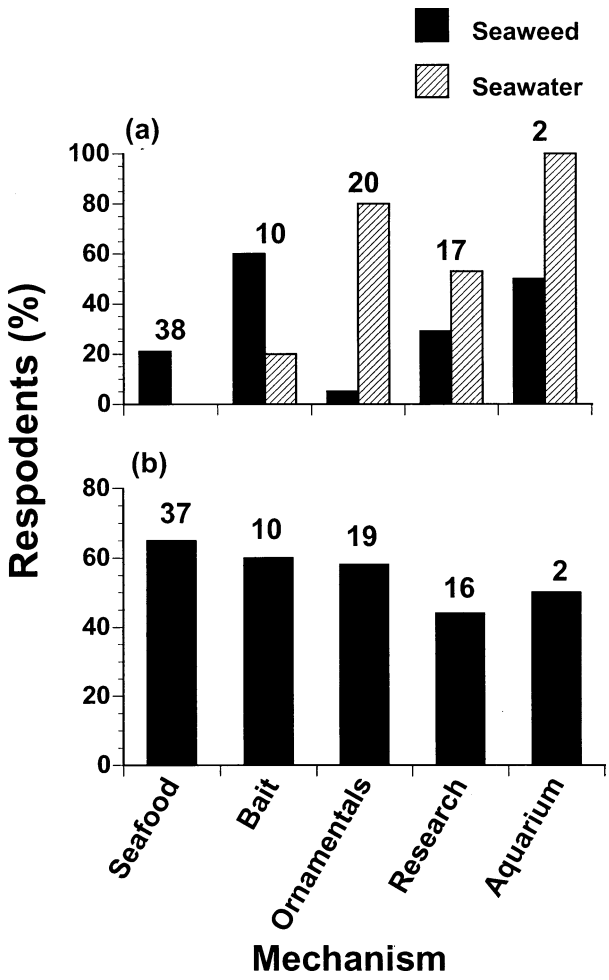


*Figure 4. Percentage of respondents importing nonlocal live or fresh marine organisms that received their products in (a) seaweed or seawater packing material and (b) who observed hitchhikers—additional nontarget plants or animals—in shipments. Total number of survey respondents per mechanism of transfer is reported above each bar.*

the live marine species trade collectively brought in large numbers of taxonomically diverse organisms to a coastal state. Of the seven sources of transfer mechanisms surveyed, five reported that they import live nonlocal marine species and, in each of these, we identified characteristics that could promote introductions. These findings are cause for concern because the volume of trade in the United States is expected to rise exponentially over the next two decades, and the number of species introductions associated with this growth is projected to increase by as much as 16–24% (Levine & D'Antonio 2003).

No transfer mechanism stood out as a primary threat for introductions. Rather, each had attributes that could lead to the establishment of exotic marine species (Table 2). Among commercial enterprises, the seafood industry was problematic for a variety of reasons, including its complex trade linkages and the multiple roles played by its constituents, the large number of operations and the proximity of nearly half of these to a body of water, the release of untreated holding-tank seawater into these waters, dockside washing of transport trucks, the use of common rather than scientific names, the huge volume of organisms imported, and a general lack of familiarity with the topic of marine invasions (Table 2). On the other hand, seafood respondents imported relatively few taxa, many of these were fresh rather than live product, imports were often indigenous to Massachusetts' waters, and species were not meant for intentional release into local waters.

Like the seafood industry, the bait industry imported few taxa, and many of these were fresh or processed product or were indigenous to local waters. Bait operations also mirrored some of the seafood industry's riskier features, including discharge of untreated holding-tank water, large amounts of imported species, and a lack of knowledge of the invasion phenomenon (Table 2). Unlike the seafood industry, live and fresh bait products were destined for release into local waters, and bait was often packed in seaweed, which could be dumped along with associated species into local waters after use.

The marine ornamentals trade differed in important respects from the seafood and bait industries. The potential high risk posed by the tremendous taxonomic diversity of marine ornamental imports was countered by the distant location of most stores from local waterways, treatment of discharged holding-tank water, the tropical origin of most species, and awareness among many store owners of the issue of bioinvasions (Table 2).

Research and public aquarium operations together comprised a smaller number of entities and imported far fewer organisms than commercial enterprises as a whole; nevertheless, opportunities for unwanted introductions existed. For example, most researchers and all public aquariums were situated next to a body of saltwater, and high percentages in each group reported receiving imports in seawater or seaweed (Table 2). Although most researchers indicated that they took care not to release live nonlocal species, a small percentage of those that kept their organisms in tanks released the water untreated into a local water body. Public aquariums had established protocols for handling nonlocal organisms, and each treated holding-tank water prior to discharge. In contrast to commercial organizations, researchers and public aquarium respondents identified imports with scientific nomenclature and were almost universally cognizant of marine invasions.

Of the dispersal mechanisms examined, only aquaculture operations and restoration projects had the explicit objectives of growing organisms in the wild. None of the respondents in either group reported importing nonlocal species to Massachusetts. In the case of the restoration projects, the use of local species appeared to be partly a

**Table 2. Summary of attributes of risk of transferring marine organisms by category for nonshipping mechanisms that imported nonlocal live or fresh marine organisms to Massachusetts.***

| | *Mechanism* | | | | |
|---|---|---|---|---|---|
| *Category* | *seafood* | *bait* | *ornamentals* | *research* | *public aquarium* |
| Number of entities | 1 | 4 | 3 | 2 | 5 |
| Opportunities for release | | | | | |
| near water (<150 m) | 3 | 4 | 5 | 2 | 1 |
| release of untreated water | 2 | 1 | 4 | 3 | 4 |
| live packing material or seawater | 5 | 4 | 2 | 3 | 1 |
| Taxonomic variety | | | | | |
| use common names | 1 | 1 | 2 | 3 | 3 |
| number of taxa | 3 | 5 | 1 | 4 | 2 |
| hitchhikers present | 1 | 2 | 3 | 5 | 4 |
| Quantity of organisms | 1 | 2 | 3 | 4 | 5 |
| Not familiar with bioinvasions | 1 | 2 | 3 | 4 | 5 |

**Mechanisms of transfer are ranked by relative counts or percentages within each surveyed category. Responses are framed so that smaller numbers denote attributes more likely to contribute to an introduction, and larger numbers, attributes that are less likely.*

matter of convenience (e.g., transporting wet seagrasses in bulk is difficult). Both mechanisms, however, remain potential conduits for marine invaders because specific restrictions on nonindigenous imports are largely absent (Office of Technology Assessment 1993; National Invasive Species Council 2001).

Our results revealed three aspects of the live marine species trade that will hinder formal risk assessment. First, with the exception of the research and public aquarium groups, most respondents used common rather than scientific names to identify imported organisms. This lack of taxonomic specificity severely limits the ability to screen marine imports for invasion potential based on life-history characteristics, environmental requirements, or previous invasion history, as has been attempted for species in other systems such as terrestrial plants ( Tucker & Richardson 1995; Reichard & Hamilton 1997; Goodwin et al. 1999; Daehler & Carino 2000) and freshwater fish (Kolar & Lodge 2002). For example, Chapman et al. (2003) acknowledged difficulty in determining the diversity of bivalve species in seafood markets of the western United States because unofficial common names were applied to multiple species. Second, a substantial percentage (44–65%) of importers in all groups reported seeing hitchhiking organisms in their shipments. The presence of nontarget organisms greatly complicates attempts to screen imports for harmful species but is rarely addressed in current models of invasion risk. Third, end-user behavior adds an unknown variable to assessment of risks posed by most dispersal mechanisms in this or any other system involving the trade of live species. For example, stores that sold marine ornamentals exhibited few high-risk features in our surveys, but the deliberate or accidental release of these organisms or aquarium water by a consumer could result in an invasion. Home release of aquarium water may have been responsible for the recent introduction of the seaweed *Caulerpa taxifolia* in southern California (Carlton 2001).

Our data suggest fundamental challenges to providing a simple, stratified ranking of dispersal mechanisms that might lead to invasions. For example, entities that transport relatively few species, such as the bait worm industry, would be considered minor in any model of risk assessment that included shipping. However, the importation of marine bait worms packed in seaweed from Maine to San Francisco Bay resulted in the introduction of a predatory crab (*Carcinus maenas*) to the Pacific coast (Carlton 2001). Thus, a minor mechanism can lead to a major invasion, underscoring the need to identify high-risk features in each mechanism rather than relying solely on classic measures such as species number or trade volume to predict risk.

The movement of live marine organisms by nonshipping mechanisms has increased dramatically in recent decades, and the trend will likely continue in coastal communities in the United States. From 1992 to 2002, foreign imports of edible seafood products into Boston, Massachusetts, rose 29.6% from 110.5 million kg to 143.2 million kg, mirroring regional and national trends (National Marine Fisheries Service 2003). Aquaculture production in the United States in 1998 amounted to nearly $1 billion, and the U.S. Department of Commerce has called for a fivefold increase in yield by 2025 (Goldburg et al. 2001). Nationally, the retail trade in marine ornamental species earned an estimated $103.2 million in revenue in 1995 (Marine Aquarium Council 2003). In Massachusetts, the New England Aquarium in Boston draws an estimated 1.3 million visitors annually, and construction of another large aquarium is scheduled in New Bedford (Weigle 2002). As coastal areas seek to balance development and habitat preservation, the number of restoration projects will undoubtedly increase. Collectively, these activities will provide economic, intellectual, recreational, and aesthetic benefits, but they also will increase the potential for invasions. Unless meaningful changes are made in importation processes, handling practices, and levels

of awareness among importers, we can continue to expect damaging introductions from nonshipping means of dispersal.

### New Management Strategies

Recent federal and state invasive species management plans have stressed the need to adopt a risk-based approach that assesses the likelihood of invasive species becoming established (e.g., National Invasive Species Council 2001). Based on our findings, we suggest a multilevel approach to limiting future invasions that includes (1) enhanced standards for water discharge, (2) more stringent requirements for reporting live species imports, and (3) industry-specific management practices designed to prevent releases.

For organizations whose product is not destined for the water, the obvious control strategy is to prevent the release of target and nontarget organisms, packing material, or holding-tank water into local waters. An existing regulatory program like the National Pollutant Discharge Elimination System (NPDES) might serve or be modified to serve such a purpose (U.S. Environmental Protection Agency 2003).

Regardless of the intended fate of live marine organisms, better records of imported species are needed. Currently, importers need to provide only the geographic origin, shipment condition, and a general description of their product to the U.S. Customs Service. In addition, these data are only kept for foreign imports; records are entirely lacking for species shipped within the continental United States. Importers of live marine species should provide documentation that includes species names, similar to that which importers of injurious species must provide the U.S. Fish and Wildlife Service.

Because the entities we surveyed showed great variability in the number and types of risky traits they exhibited, management practices should be tailored to each type of transfer mechanism. For example, seafood companies that handle live shellfish require more scrutiny than those handling fresh finfish. Furthermore, regional aspects of the trade should be taken into consideration. Tropical plants and animals imported by the marine ornamentals industry may pose little risk if they escape into the cold waters off New England, but they represent a much greater threat if released in Florida.

As a starting point, stakeholders need to exchange information, so that innovative solutions can be disseminated. For example, using methods drawn from the Hazard Analysis Critical Control Point (HACCP) program, Sea Grant has worked with companies in the freshwater aquaculture industry to identify alternative product handling and packaging measures to decrease the risk of exotic species introductions. Such methods could easily be adapted to include industries that work with marine species (Gunderson & Kinnunen 2001).

## Conclusion

Finally, how do nonshipping and shipping dispersal mechanisms compare as agents of marine introductions? Nonshipping mechanisms as a group and the shipping industry both move a tremendous number and variety of species from diverse geographic origins. They differ, however, in a number of important respects. The trade in live marine species is primarily moving postlarval organisms, and these are meant to arrive in good condition. In contrast, organisms transported in ships' ballast water are often larval forms or algal spores that can suffer high mortality in transport (Smith et al. 2001; Wonham et al. 2001). Consequently, per capita survival may be greater for organisms released by nonshipping than by shipping mechanisms. Direct releases, however, are not practiced industry-wide by most nonshipping mechanisms; thus, the quantities of organisms entering coastal waters are probably orders of magnitude smaller than those transferred by commercial ships. To date, most regulatory efforts have been directed toward ballast-water management (National Invasive Species Act of 1996). It is a mistake, however, to dismiss the risks posed by nonshipping mechanisms. A valuable next step would be to assess how the patterns we detected in Massachusetts in the trade of live marine organisms compare with patterns in other areas of the nation and the world.

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