A Primer on Invasive Species In Coastal and Marine Waters

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Acknowledgments

We thank Mike Spranger for his encouragement throughout the development of this primer. Steve Kearl and Dorothy Zimmerman provided valuable editorial input.

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Funding and support

This publication was supported by the National Sea Grant College Program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) under NOAA Grant No. NA16RG-2195. The views expressed are those of the authors and do not necessarily reflect the views of these organizations.

The Florida Sea Grant College Program, the Southeast Regional Aquatic Nuisance Species (ANS) Education and Outreach Network, a partnership between the Sea Grant College Programs in Alabama, Florida, Louisiana, and Mississippi, UF/IFAS Extension and the University of Central Florida provided support for the development of this document.

Additional funds to support publication of this document were provided by the Tampa Bay Estuary Program.

Photo credits

Cover, upper left: *Phyllorhiza punctata*, an Indo-Pacific jellyfish now found in large numbers around the Gulf of Mexico. (Photo courtesy Dauphin Island Sea Lab)

Cover, center left: *Perna viridis*, an Indo-Pacific mussel that became established in Tampa Bay and has spread around Florida and into Georgia. (Photo courtesy U.S. Geological Survey)

Cover, lower left: *Pterois volitans*, an Indo-Pacific fish often kept in saltwater aquaria that is now found along the east coast of the United States. (Photo courtesy J.E. Randall)

Cover, bottom half: Aerial photograph of an explosion of the Australian spotted jellyfish (*Phyllorhiza punctata*) in the Gulf of Mexico. (Photo courtesy Dauphin Island Sea Lab)

Page 1, upper right: *Pterois volitans*, an Indo-Pacific fish often kept in saltwater aquaria, is now found along the east coast of the United States. (Photo courtesy J.E. Randall)

July 2004

What are invasive species?

Invasive species have entered an area that is not part of their natural range. They represent one type of alien, non-native, nonindigenous or introduced species. In contrast, native or indigenous species occur in an area naturally. Invasive species that are native or introduced differ from beneficial native and non-invasive species because they can or do cause harm to the economy, the environment or human health. Typically, invasions involve the spread of an introduced species. Natural vectors, such as storms, or vectors associated with human activities may cause introductions and subsequent invasions by moving species along pathways. Human introductions may be intentional or unintentional, and both types of introductions can cause bioinvasions. We can add a political bent to the discussion by applying the term exotic to species that have entered a new country and using the term transplanted for species moved to new areas within the same country.

Whatever definitions we choose, we should all be concerned about invasive species and the harm they cause. First, we want to avoid harmful consequences from introductions. Second, our actions or activities can spread invasive species, so we are responsible for managing both introductions and any consequences. Managing invasive species will not simply be a matter of banning all introductions because all of us benefit from some introductions and many introductions are accidental or unintentional. We can improve our management of invasive species by looking at the history of species introductions, the harm caused by invasive species, how invasive species are introduced and become invasive, and how we can manage our own actions and activities to help solve the problem.

How long have invasive species been around?

People began introducing species as soon as they could travel. For example, beginning around 1500, Europeans transported Old World species to their new settlements in the Western Hemisphere and elsewhere. The manifests from Columbus' second and subsequent voyages indicate deliberate transport of species regarded as potential crops and livestock.

Humans continue to disperse species, and the worldwide increase in plant, animal, and microbial introductions roughly tracks the increase in human transport and commerce. In particular, the meteoric growth of global commerce in the past 200 to 500 years has produced numerous opportunities for biotic invasions. During this time span, the scope, frequency and impact of people's deliberate and accidental movements of organisms undoubtedly dwarf the effects of natural forces during any 500-year period in the earth's history. For example, introductions to coastal habitats in the United States have increased over 100-fold in the last 200 years (Figure 1).

People apply a confusing and muddled collection of words to invasive species.

A glossary found on pages 14 and 15 provides definitions for key terms used in this publication.

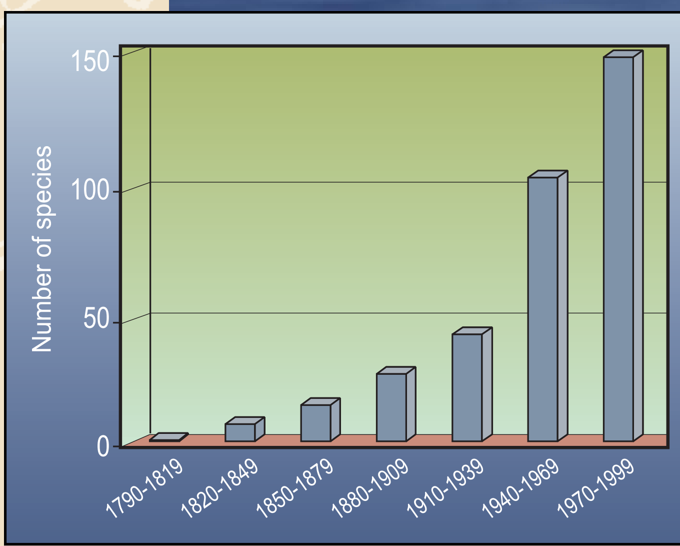


Figure 1. Rate of new invasions by marine invertebrates and seaweeds in the U.S. coastal zone from 1790 to 1999 (374 total invasions). Source: Ruiz et al., 2000; Carlton, 2001.

Box 1.

Deliberate and accidental introductions of invasive species.

- deliberate introduction of few, if any, invasive microorganisms, although we introduced yeasts for fermentation and mutualists, such as the symbiotic, mycorrhizal fungi found in plant roots
- deliberate introduction of some insects that have caused adverse consequences, such as bumblebees in New Zealand, but the majority of invasive insects have probably been introduced accidentally
- deliberate introduction of a few marine invertebrates, such as the Pacific oyster imported from Japan to Washington state, but a growing number of invaders, such as the zebra mussel, have arrived accidentally as contaminants in ballast water and through other vectors
- deliberately introduced most invasive vertebrates, principally fish, mammals and birds, although some of the worst vertebrate invaders have been spread accidentally, such as rats, brown tree snakes and sea lampreys
- deliberately introduced many, if not most, plant invaders, including water hyacinth, melaleuca trees, salt cedar and other serious pests, although some invasive plants have been accidentally introduced as contaminants among crop seeds and other cargo

Throughout history, we have accidentally and deliberately introduced numerous species. Our tendency to accidentally or deliberately introduce invasive species varies among types of organisms (Box 1). The number of deliberately introduced species that become invasive emphasizes the fact that not all pests arrive unheralded and inconspicuously. Many of our worst problems are the product of our own deliberate but flawed plans.

What harm do invasive species cause?

Introduced species typically do not survive and reproduce; therefore, they seldom establish themselves and become invasive (Figure 2). Introductions can be viewed as an ecological parallel to Russian roulette. We 'load bullets into a gun and spin its cylinder' by moving species beyond their natural ranges. Then, we 'pull the trigger' by introducing species into

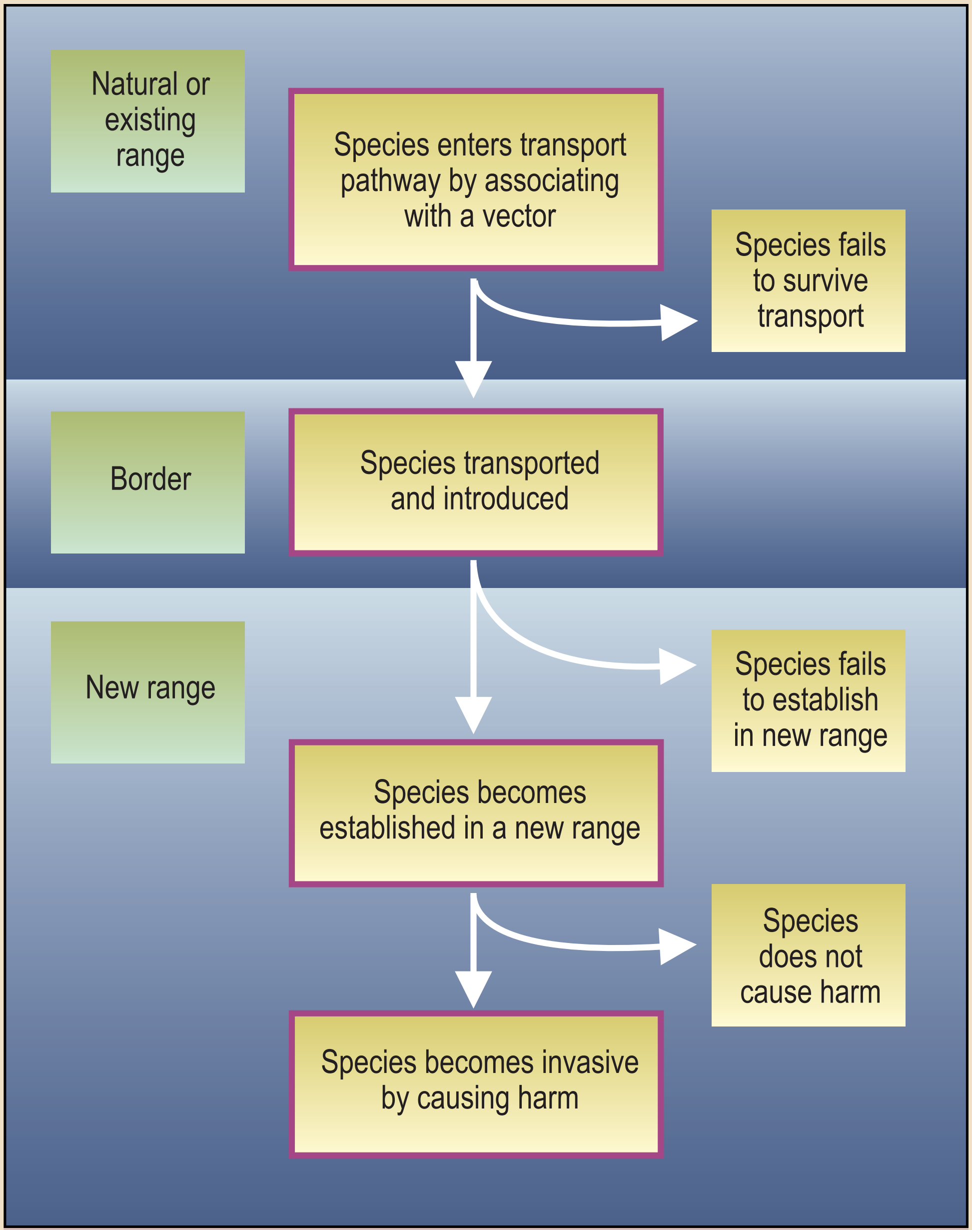


Figure 2. Steps in becoming an invasive species.

new ranges and take our chances on whether they cause harm by establishing and spreading. As in any game of chance, the outcome of a given round is uncertain. We may introduce numerous species or one species numerous times and suffer no significant consequences, or we may introduce a single species once and generate immense harm. In general, species cause harm by affecting plant and animal populations or communities, ecosystems and ecosystem services, or our economy.

Effects on populations

Invasive species often affect populations or interbreeding groups of organisms. They typically cause extirpation or losses at the local level, but they possess the potential to cause extinction or losses at the global level. Extinction becomes a very real possibility for endangered, threatened or rare species. Invasive species typically affect native populations through six types of ecological interactions (Box 2).

Invasions by pathogens can severely impact native species. For example, we all know of plant diseases that have spread readily, especially those that affect crops, livestock or pets. We also could include effects on human health here, such as concerns about ballast water introducing cholera in places it is not normally found.

Invaders can directly remove native species by predation and grazing. Historically, people have introduced many animals in attempts to make new places more like 'home.' Even today, we continue to release domesticated animals into new places where they can cause significant harm.

Nonindigenous species also harm natives by competing for scarce resources in what ecologists call scramble competition. Invasive species often seem capable of out competing native species by sequestering water, nutrients or food more efficiently. For example, invasive plants typically out compete natives by shading them or using scarce water.

When a species interferes with or harms another in the competition for resources, ecologists call it interference competition. Invasive species clearly demonstrate this tactic. For example, many invasive animals exhibit aggressive behavior that drives native animals out of their natural ranges, and invasive plants may produce toxins (phytotoxins) that inhibit the success of native plants.

Invasive species can also eliminate native species by hybridizing with them. Such interbreeding is a particular danger when the native populations are endangered, threatened or rare. Hybridization between a nonindigenous species and a native one can even produce a new invasive species. In addition, hybridization can threaten a native species even when the hybrids die, simply because crossbreeding reduces the number of new offspring added to the species' own population.

Finally, invasive species can evolve new ways to threaten natives after establishment. Plants and animals exhibit remarkable capacities to develop resistance or other ways to overcome the defenses erected by native species.

Effects on communities, ecosystems and ecosystem services

In the direst situations, invasive species threaten to disrupt both communities, which are formed by groups of populations, and entire ecosystems, which are natural systems that produce and recycle

Box 2.

Examples of how invasive species harm populations.

- Asian chestnut blight fungus arrived in New York City on nursery stock early in the 20th century and, within a few decades, the blight had spread and destroyed almost all the American chestnuts that had once dominated forests in the eastern United States (disease)
- predatory Nile perch introduced into Africa's Lake Victoria has eliminated or gravely threatens more than 200 of the 300 to 500 native species of small, cichlid fishes (predation)
- feral and domestic cats introduced to every part of the world have depleted breeding populations of seabirds and endemic land birds on oceanic islands and contributed significantly to the extinction of six endemic birds in New Zealand and at least six species of Australian rodent-like marsupials (predation)
- North American gray squirrels replace the native red squirrels in Britain because they forage more efficiently (scramble competition)
- succulent ice plant, *Carpobrotus edulis*, forms a mat that shades native plants in coastal California and removes scarce water that the native species need (scramble competition)
- introduced ant species – the red fire ant, the Argentine ant and the big-headed ant – all significantly reduce native ant populations by aggression (interference competition)
- Quackgrass damages crops, and it may do so by producing phytotoxins (interference competition)
- hybridization with the introduced North American mallard threatens the genetically distinct existence of both the New Zealand gray duck and the Hawaiian duck (interbreeding)
- North American cordgrass, carried in shipping ballast to southern England, hybridized with native cordgrass and one hybrid underwent a genetic change to produce a fertile, highly invasive species of cordgrass (interbreeding)
- females of the European mink, already gravely threatened by habitat deterioration, hybridize with males of introduced North American mink resulting in aborted embryos and a loss of eggs that exacerbates their decline (interbreeding)
- parasitic wasps imported to the United States to control the alfalfa weevil were originally ineffective against the Egyptian alfalfa weevil, but, fifteen years later, the wasps appeared to have evolved a resistance because 95% of their eggs were surviving in the larvae of the Egyptian alfalfa weevil (evolution)

Box 3.

Examples of how invasive species harm communities, ecosystems and ecosystem services.

- Australian paperbark or melaleuca trees replaced cypress, sawgrass and other south Florida natives at the rate of 20 hectares per day resulting in about 160,000 hectares that provides poor habitat for many native animals, uses huge amounts of water, and intensifies fire regimes
- a vine-like perennial shrub from South America, *Chromolaena odorata* or Siam weed, aggressively suppresses regeneration of primary forest in both Asia and Africa and provides feeding niches that sustain other pests
- a highly invasive neotropical shrub, *Lantana camara*, increases the occurrence of sleeping sickness among animals and humans by serving as additional habitat for the tsetse fly that normally lives along East African streams
- a small tree native to the Canary Islands, *Myrica faya*, is transforming the entire ecosystem in Hawaii Volcanoes National Park by fixing nitrogen and causing a 90-fold increase in supplies of this scarce nutrient, which encourages many other introduced plants to enter the ecosystem
- *Myrica* also attracts the introduced Japanese white-eye, the most destructive bird invader in native Hawaiian forests, and the white-eye exacerbates ecosystem changes by dispersing *Myrica* seeds
- the Bluegrass Country of Kentucky invokes images of a pastoral or pristine setting; however, bluegrass is a Eurasian invader introduced during European settlement and land clearing after which it replaced the original open forest, savanna, and understory of wild rye and possibly canes
- burning of forests and introduction of African grasses to the Amazon basin creates grasslands that contain much less plant biomass and sequester less carbon, which could exacerbate the buildup of carbon dioxide in the atmosphere and influence the global climate

more energy and other resources than they import (Box 3). Invasive plants demonstrate these threats best. Typically, invasive plants change ecosystems by using significant amounts of water, occupying space and shading natives, providing poor habitat and forage for native animals, or altering fire regimes. In fact, many invasive plants wreak havoc on ecosystems by fostering more frequent or intense fires that they withstand better than key native species. The paperbark tree, a *Melaleuca* species, has this effect in Florida, as do numerous invasive grasses worldwide. Grasses, in particular, produce a great deal of flammable standing dead material, dry out rapidly, and resprout quickly after fires.

Invasive plants may also alter ecosystems in more insidious ways. For example, they may change the cycling of nutrients in a way that encourages invasions by other plants, or they may promote invasions by non-native animals. In some cases, alien plants and animals combine to create a positive feedback loop with the plant providing food for the animal and the animal distributing the plant's seeds.

In some places, invaders cause ecosystem changes that profoundly alter the landscape and the ecosystem services we value. For example, bluegrass in Kentucky and some other ecosystems we take for granted in the United States are actually a result of successful invasions by species introduced by colonists. Overall, our knowledge of invasions is poor, but known invasions raise the concern that the current pace and extent of invasions may significantly influence other agents of global change in an unpredictable manner. For example, we may alter the global carbon cycle by converting diverse forests to grasslands. Grasses create less tissue or biomass so they use and sequester less carbon dioxide. Less carbon in plants means more carbon dioxide in the atmosphere, which may accelerate global warming and the attendant consequences.

Effects on economies

Public and governmental support for the prevention or control of invasions often falters because most people don't understand or appreciate the complex links between nature and our economies. Invasive species pose threats to biodiversity and processes in ecosystems, and these threats translate directly into economic consequences, such as losses of crops, forests, fisheries and grazing lands. However, the economic consequences of biotic invasions are poorly explored and quantified. Although we have anecdotal evidence of local and even regional costs from invasive species, we lack clear, comprehensive information on these costs at national and global levels.

Biotic invasions cause three main types of economic impact. First, invasive species reduce potential economic output by reducing the production, survival and fitness of crops, domesticated animals and fisheries. Second, we suffer direct costs associated with combating invasions, including all forms of quarantine, control and eradication. Combating invasive species that are threats to human health, either as direct agents of disease or as vectors or carriers of disease-causing parasites, represents a third category of costs.

These costs form a hidden but onerous 'tax' on many goods and services. Tallying these costs represents a formidable task. One group recently attempted to tabulate the annual cost of all nonindigenous species in the United States. They estimated that nonindigenous weeds that affect crops cost agriculture about $27 billion per year, based on a potential crop value of $267 billion. Loss of forage and the application of herbicides to weeds in rangelands, pastures and lawns cost a further $6 billion each year. When the group combined these types of direct losses with indirect costs for activities such as quarantine, the total cost of all nonindigenous species (plants, animals and microbes) exceeded $138 billion per year. By any standard, such costs are formidable, even for a productive, industrialized society such as the United States.

These estimates illustrate the anecdotal and preliminary nature of our current understanding of the economics of invasions. One solution would be a more frequent application of economic tools such as cost:benefit analysis when considering proposals to import species for perceived economic benefit. When it comes to future movements of species, society needs to consider results from analyses like those provided for hydroelectric dams, canals, airports, and other projects with potential environmental consequences. Scientists predict that cost:benefit analysis of many deliberately introduced invaders would demonstrate forcefully that their costs to society swamp any realized or perceived benefits.

Those are terrestrial and freshwater examples. What about impacts on coastal and marine waters?

The economic and ecological effects of coastal and marine introductions are notoriously difficult to estimate, and detailed estimates have not been made for the waters of the United States. In any estimate, negative and positive effects must be considered. Negative effects include revenues lost due to the destruction of fisheries; loss of other resources due to predation, competition, or disease; the cost of removing introduced fouling organisms from hundreds of thousands of recreational vessels; and the costs associated with the damage to pilings and other structures by introduced wood-borers. Positive effects include the value of fisheries based on non-native species and the aesthetic value of introduced species, even if the public does not know that the species are introduced. A further challenge is estimating the potential effects of cryptogenic species whose origins are uncertain. For example, we are uncertain about the origins of 'killer dinoflagellates' in the genus *Pfiesteria* and many toxic algal blooms or red tides. Overall, information indicates that coastal and marine introductions have vast negative effects on the economy of the United States. In addition, funds diverted to research and control of introduced species could have been used for other purposes. Between 1999 and 2001, the costs for research and control related to three Pacific coast introductions equaled nearly one-third of all the funds available through the Sea Grant College Program for an entire decade of research and education on introduced species.

Although poorly documented, introduced marine species fundamentally alter the biodiversity of coasts in the United States and around the world. Invasive species often out compete native species either in a scramble for resources or through interference competition. In some ecosystems, the introduced species become so dominant that finding native species becomes an elusive goal. Overall, the effects of introduced species rank second to habitat destruction as a threat to biological diversity. Communities and ecosystems are also affected by introductions of new predators, competitors, disturbers, parasites and diseases. These introductions lead to vast alterations in species interactions and to changes in nutrient cycling and energy flow that result in cascading and unpredictable effects throughout entire communities. Although no one has determined the actual economic impact, certain indicators suggest that species introduced into coastal and marine systems may cost the United States hundreds of millions of dollars every year.

Although our knowledge of impacts from introductions is poor, we now know that numerous species have been or are being introduced to the coastal and marine ecosystems of the United States (Box 4). Hundreds of introduced species occur in the United

Box 4.

Facts about marine invasions.

- a tropical seaweed, *Caulerpa taxifolia*, developed tolerance for colder temperatures while growing in public and private aquaria in Europe, and, when it escaped into the northwest Mediterranean, its new tolerance of winter temperatures helped it blanket large stretches of the seafloor and threaten nearshore plant populations
- the European periwinkle, introduced to Nova Scotia around 1840, grazes heavily on shoreline plants that trap and hold sediments. As a result, many coastal inlets transformed from mudflats and salt marshes to rocky shores
- introduced species foul jetties, marinas and buoys with the result being changes in food webs and energy flow that further stress troubled fisheries
- introduced species of crabs, mussels, clams, jellyfish, seagrasses and marsh grasses form conspicuous parts of marine ecosystems from the Hawaiian Islands to the Pacific Northwest, south to San Francisco Bay and southern California, east to the Gulf of Mexico, and north to Chesapeake Bay and New England
- Puget Sound, in Washington State, Coos Bay, in Oregon, and Chesapeake Bay, in Virginia and Maryland, harbor at least 50, 60 and 43 non-natives respectively
- more than 175 species of introduced marine invertebrates, fish, algae and higher plants live in San Francisco Bay alone
- in San Francisco Bay alone, an average of one new introduction becomes established every 14 weeks between 1961 and 1995
- new introductions and establishments occur in the United States in 2000–2001, with:
    - vast numbers of Pacific spotted jellyfish (*Phyllorhiza punctata*) invading the Gulf of Mexico
    - billions of small carnivorous, European flatworms (*Convoluta convoluta*) appearing in the Gulf of Maine
    - the Asian whelk (*Rapana venosa*) becoming more abundant in Chesapeake Bay
    - the Japanese mahogany clam (*Nuttallia obscurata*) reaching southern Oregon
    - the brown mussel (*Perna perna*) invading the Gulf of Mexico
    - thousands of Asian shore crabs (*Hemigrapsus sanguineus*) in Long Island Sound
    - the Mediterranean green seaweed (*Caulerpa taxifolia*) and the Asian kelp (*Undaria pinnatifida*) appearing in southern California
    - thousands of farmed Atlantic salmon (*Salmo salar*) escaping into the Pacific

Box 5.

How many and what kinds of species occur in ballast water?

- studies in the United States, Germany, Scotland, Wales, Australia and Hong Kong, reveal that ballast water can contain representatives of all major and most of the minor groups of marine life
- many species travel as larval, or dispersal, stages, and then they become bottom-dwelling organisms as adults
- examples of commonly transported species include sea anemones, worms, barnacles, crabs, snails, clams, mussels, oysters, bryozoans, sea urchins, sea squirts and algae
- other species, such as diatoms, dinoflagellates, copepods and jellyfish, travel as adults in ballast water
- certain viruses and the bacteria that cause cholera epidemics have also been detected in ballast water
- overall, organisms in ballast water range in size from microscopic viruses and bacteria to fish 12 inches (30 cm) or longer
- we probably transport at least 7,000 different species of marine life in ballast water each day
- ballast water, carrying all these non-native species arrives in the United States at the rate of 2 million gallons per hour

States' waters, and the rate of known introductions has increased exponentially since the 18th century, with no signs of leveling off. Unfortunately, the exact number of coastal and marine introductions remains unknown for a variety of reasons. For example, we seldom know the origin and history of coastal or marine species. Scientists probably overlook introductions of both microscopic species and groups of organisms that are difficult to identify. Some introduced species are cryptogenic, which means they look similar to native species and can only be distinguished by genetic analyses. A decline in coastal and marine exploration and reduced training in systematics and taxonomy contribute to confusion about the precise number of marine introductions. Overall, we seem determined to play ecological roulette with introductions of marine species.

How are species introduced into coastal and marine systems?

Every day, a large number of human-mediated vectors move thousands of coastal or marine organisms around the world and introduce them into new areas. Recent events underscore the need for effective education and management programs that increase awareness of how our activities result in introductions. Species arrive in United States' waters from virtually every region of the world after traveling along numerous trade routes that continuously change. At a given coastal site in the United States, our activities and actions create the potential for numerous, repeated and frequent introductions of non-native species. An examination of some of the key vectors illustrates the extent and depth of the challenges we face.

Ballast water and fouling organisms from ships

Today, more than 45,000 commercial, cargo-carrying vessels and hundreds of thousands of recreational vessels ply the world's seas. These vectors transport a diverse array of marine life at unprecedented rates (Box 5). In a variety of ways, these vessels carry living aquatic organisms from fresh, brackish or marine water, across and between oceans, or along coastlines. An arriving vessel may be a virtual 'floating biological island,' with hundreds of species living both on and in the ship.

Since the 1880s, most ships carry ballast water. Ballast water pumped or fed by gravity into a vessel compensates for the lack of cargo, maintains the trim and draft of the vessel, and enhances stability and operational efficiency. Most ships, even those with cargo, carry some ballast water. A ship may take on ballast water in port or at sea. The water is held in ballast tanks or floodable cargo holds. A ship may discharge all or some of its ballast water when it arrives at its next port. Before water became commonly used as ballast, ships were loaded with rocks, sand, soil or almost anything cheap and heavy. Movement of 'dry ballast' spread thousands of species of insects and other arthropods, mollusks and plants. In contrast, ballast water tends to spread saltwater species from four communities:

- plankton: organisms that drift passively or swim modestly;
- nekton: species that swim freely;
- fouling: organisms (including bacterial films) that attach to the vertical walls and horizontal structures in the ballast compartments; and
- benthos: organisms that dwell on the bottom, such as beds of marine worms and associated species and the encysted, or resting, stages of plant plankton (phytoplankton) and animal plankton (zooplankton).

Ballast is not the only means by which ships carry marine life from foreign shores to the United States. Fouling organisms attached to the outside of vessels can also invade new regions. For the past 500 years, tens of thousands of vessels have formed a conveyor belt between North America and the rest of the world by transporting species that could not survive drifting on their own across the high seas. Historically, barnacles, mussels, hydroids, algae and other marine organisms formed fouling assemblages thick enough to harbor free-living species, such as crabs and fish. Modern ships continue to carry fouling organisms on their hulls, rudders, propellers and propeller shafts, as well as in seawater piping systems (including ballast intake screens) and their sea chests, the water compartments between the outside of ships and the ballast pumps. Sea chests, in particular, accumulate organisms that would not survive on the hull of the ship, and they are now suspected of playing a significant role in introductions. Antifouling paints, which are toxic to marine life, discourage or prevent the attachment of fouling organisms. Regulations that protect the environment by decreasing use of certain paints may increase the presence of fouling populations. For example, paints containing tributyl tin (TBT) probably will be banned internationally. In Australia, decreased use of paints with TBT has already increased ship fouling. Further studies are needed to determine if there is a correlation between decreased use of TBT-based paints and increased introductions from ship fouling.

Both ballast water and ship fouling may combine to introduce some species of marine life. Ballast water and the organisms in it are introduced when they are discharged as a ship loads cargo. Organisms attached to ships' hulls or sea chests must reproduce, become dislodged or swim off the ship in order to be introduced. Many organisms, including barnacles, mussels, hydroids, sea squirts and algae, can be introduced by both mechanisms.

Dry docks, drilling platforms and maritime activities

Increases in international commerce and reliance on offshore oil, gas and other resources generate a concomitant increase in the movement of dry docks used to float and repair ships and semi-submersible, self-propelled drilling and production platforms used for discovery and extraction of resources. These structures have abundant subsurface space for fouling communities and ballast water systems.

Other maritime activities can also transport and introduce species. Examples include the long-distance movement of navigation buoys, marina floats, amphibious vessels and seaplanes.

Fisheries activities

Marine life is dispersed through a wide range of fisheries activities (Box 6). These activities fall into two broad categories: intentional releases, whether legal or illegal, and accidental releases.

The wisdom of deliberately introducing non-native species has been debated for a long time. In the 19th century, many 'acclimatization societies' and government agencies intentionally released non-native species into United States' waters to 'improve nature' or start new fisheries. Today, we make far fewer purposeful attempts to sprinkle exotic marine species into the wild. Current proposals to introduce species often focus on using individuals that cannot reproduce because they are sterile or because temperatures and other conditions for reproduction are not right. Concerns remain because individuals could adapt to new temperature regimes and other conditions, and individuals may not remain sterile. Regardless, people still deliberately transport an unknown number of species and individuals on a daily basis. These animals are transported for direct consumption as live seafood, for use as live bait with 'freshening' in the marine environment, or with the intent or hope of starting a new fishery. We have no data on the scale of illegal attempts to start new fisheries by introducing species.

Box 6.

Examples of introductions related to fisheries activities.

- intentional introduction of Atlantic striped bass (*Morone saxatilis*) to the Pacific coast in the 1870s represents a striking example of creating a new fishery
- live Atlantic lobsters (*Homarus americanus*) purchased at the airport in Boston or New York are released in southern California waters hours later by people who would prefer to let the shellfish live rather than eat them
- seaweed used to pack bait-worms from the Atlantic coast apparently leads to the introduction of the European shore crab (*Carcinus maenas*) on the Pacific coast
- live and healthy softshell, blue crabs (*Callinectes sapidus*) from Chesapeake Bay have been bought in San Francisco fish markets and occasionally released into California waters by the public
- proposals to revitalize the waning oyster industries in the Gulf of Maine and Chesapeake Bay have focused on the use of non-native species with resistance to the diseases that killed native Chesapeake Bay oysters
- Virginia placed sterile stocks of the Japanese oyster (*Crassostrea ariakensis*) in Chesapeake Bay in 2001
- Maryland did not participate in the stocking experiment because of potential liabilities if some individuals revert to a reproductive state, establish wild populations and spread to states and jurisdictions that do not want non-indigenous oysters
- this incident points out the difficulties of managing introduced species under the current regulatory system

Such attempts may be a significant source of introductions, given the ease with which people bring living organisms into the United States in their luggage.

The distinction between intentional and unintentional introductions becomes blurred when we include innumerable incidents in which the public releases living, nonindigenous organisms without any particular future intent. After a day's fishing, fishermen may discard leftover bait-worms and the seaweed they were packed in, which contains numerous other live organisms that can become invasive. As a vector, fishermen move relatively small amounts of material and few species, but they demonstrate that a small vector may not be a minor one if it leads to major introductions. This situation raises the challenge of whether to prioritize management according to the volume of traffic through a vector or the number of species that are transported. The sale of live seafood in markets where it is not native represents another troublesome vector. Laws may require private persons or public agencies to obtain permits before releasing animals to deliberately start a fishery, but seafood consumers can release animals without being aware of or affected by such requirements.

Aquarium industry and the availability of living marine organisms on the Internet

In the United States, the aquarium industry sells an unknown number of invertebrates, fish, algae and seagrasses as 'pets' or 'displays.' Tropical and subtropical species form the bulk of the imports, but temperate species are also traded. A few species are regulated, such as piranhas, but most imports are not restricted. Although the organisms are not imported for release into the wild, in the southern half of the United States, subtropical and tropical fish represent an abundant and diverse component of fish communities. Data indicate that accidental or deliberate releases of aquarium species may contribute to this situation (Figure 3).

In addition to marine life available for home aquaria, a long list of other marine organisms can be purchased for education and research on scores of websites. The fate of these organisms remains largely in the hands and control of the public, educators or researchers with few, if any, regulatory constraints and little or no information about the potential consequences of accidental or deliberate releases.

Other vectors

A variety of additional vectors, such as disposal of dredge spoil, beach renourishment and movement of recreational equipment, have been invoked at one time or another to explain the appearance of new species. The significance of these vectors may vary regionally or locally, with bursts of activity related to special or focused events. Biocontrol, or the release of one species to control another, has not been tried in the oceans, but it is increasingly a topic of discussion.

Floating marine debris as a potential vector for introductions represents another area of increasing concern, especially in the Pacific Ocean. Large numbers of fishing nets drift in the Pacific and come ashore covered with marine organisms in places like the Hawaiian Islands.

Coastal dispersal of introductions

Once a new species has arrived and become established in the United States, it may disperse along the coastline by natural means. It may float or drift as a planktonic larva, or it can be

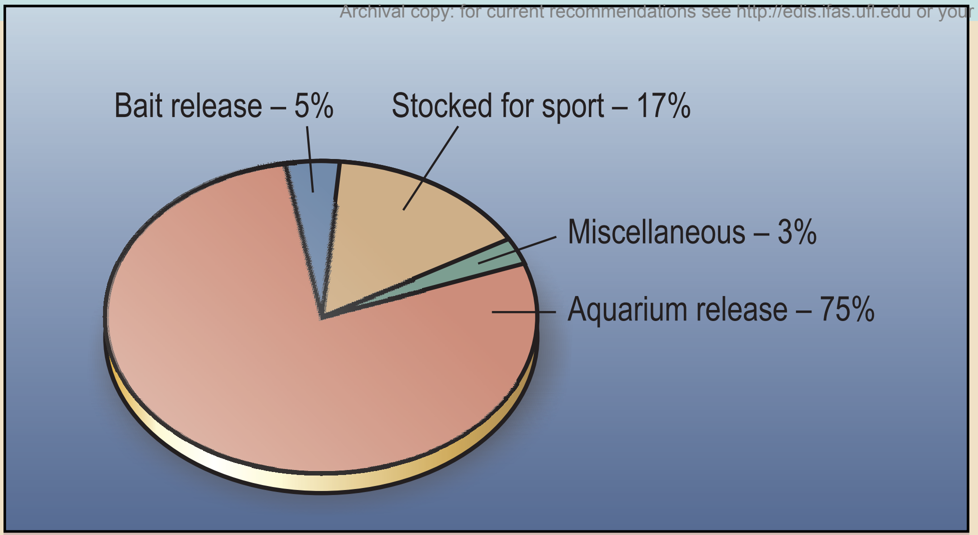


Figure 3. Sources of introductions in Florida. The large contribution by aquarium releases is unusual. Source: USGS, 2001.

attached to floating materials such as seaweeds, seagrasses, and marine debris. Human-mediated vectors can also transport a new species alone or in combination with natural means.

Most research efforts focus on mechanisms that could bring new, exotic species into United States' waters. As a result, few data adequately describe or quantify how new invaders spread along a coastline. Such data are critical to predict both the rate and direction of spread.

The number and diversity of transport vectors

In the past 200 years, the number of vectors transporting marine species has steadily increased. In 1800, only two mechanisms, ship-hull fouling and ballast rocks, were available to move the European shore crab (*Carcinus maenas*) across or between oceans. By 1900, three additional mechanisms became available: ballast water, intentional movement as food, and the importation of oysters for aquaculture. By the year 2000, ten human-mediated mechanisms could move the crab around the world. Six new vectors were added to the previous vectors with ballast rocks being no longer used. Crabs were moved as bait, as aquarium species, as part of the school-educational market, as research animals, accidentally with lobster shipments, and along with petroleum production platforms.

The stage for new invasions is constantly set and reset because numerous transport mechanisms come into play on an hourly basis. Numerous ships and seaplanes reach coastal sites in the United States. Marina floats drift in from distant harbors. Live, non-native, marine organisms are purchased for food, for use as bait or as pets. Educational institutions, research institutions and public aquaria hold a large variety of living, exotic, marine organisms. A large seafood restaurant overlooking the water imports live Maine lobsters, wrapped in fresh, invertebrate-laden seaweed. In a nearby salt marsh or estuary, restoration of important plants may be underway, using stocks and sediments shipped from distant locations. Today, more species and more individuals of those species are transported because of the increasing diversity of vectors. Moreover, the fact that most species can now be introduced by many different vectors makes the prevention of introductions an even greater challenge.

Box 7.

Generalized characteristics of successful invasive species.

- high rate of reproduction
- colonizing disturbed habitats before other species
- short generation time
- long life span
- high dispersal rate
- single-parent reproduction by a female that has eggs or is pregnant
- asexual reproduction
- high genetic variability
- phenotypic plasticity, which means it changes form in response to environmental conditions
- broad native range
- abundant in native range
- tolerant of a wide range of conditions
- habitat generalist, which means it lives in a variety of habitats
- broad diet
- gregarious, which means it lives in groups
- benefits from living with humans without causing us harm, that is lives as a commensal

Box 8.

Generalized characteristics of habitats susceptible to invasion.

- climatically similar to the original habitat of invader
- recently disturbed by humans or natural events
- low diversity of native species
- absence of predators that will eat the invading species
- absence of native species similar in ecology or morphology (form or structure) to the invader
- absence of predators or grazers similar to the invader so food sources are naive
- absence of fire so the invader will not need to adapt to this disturbance
- simple food web with few connections so the invader will not be competing with many other species

Why can't we just exclude potential invaders?

Management of invasive species would be far simpler if we could identify potential invaders and where they might become established before we have a problem. Scientists have listed characteristics of both potential invaders (Box 7) and places susceptible to invasion (Box 8), but using these generic lists to manage invasive species proves to be difficult.

Applying the generic lists proves to be difficult because:

- species may only display one of the typical characteristics;
- many species do not display any of the characteristics in their native habitat;
- invasions may involve a particularly invasive species, a particularly vulnerable habitat, or both; and
- the causes of most invasions are unknown because they were noticed only after they occurred.

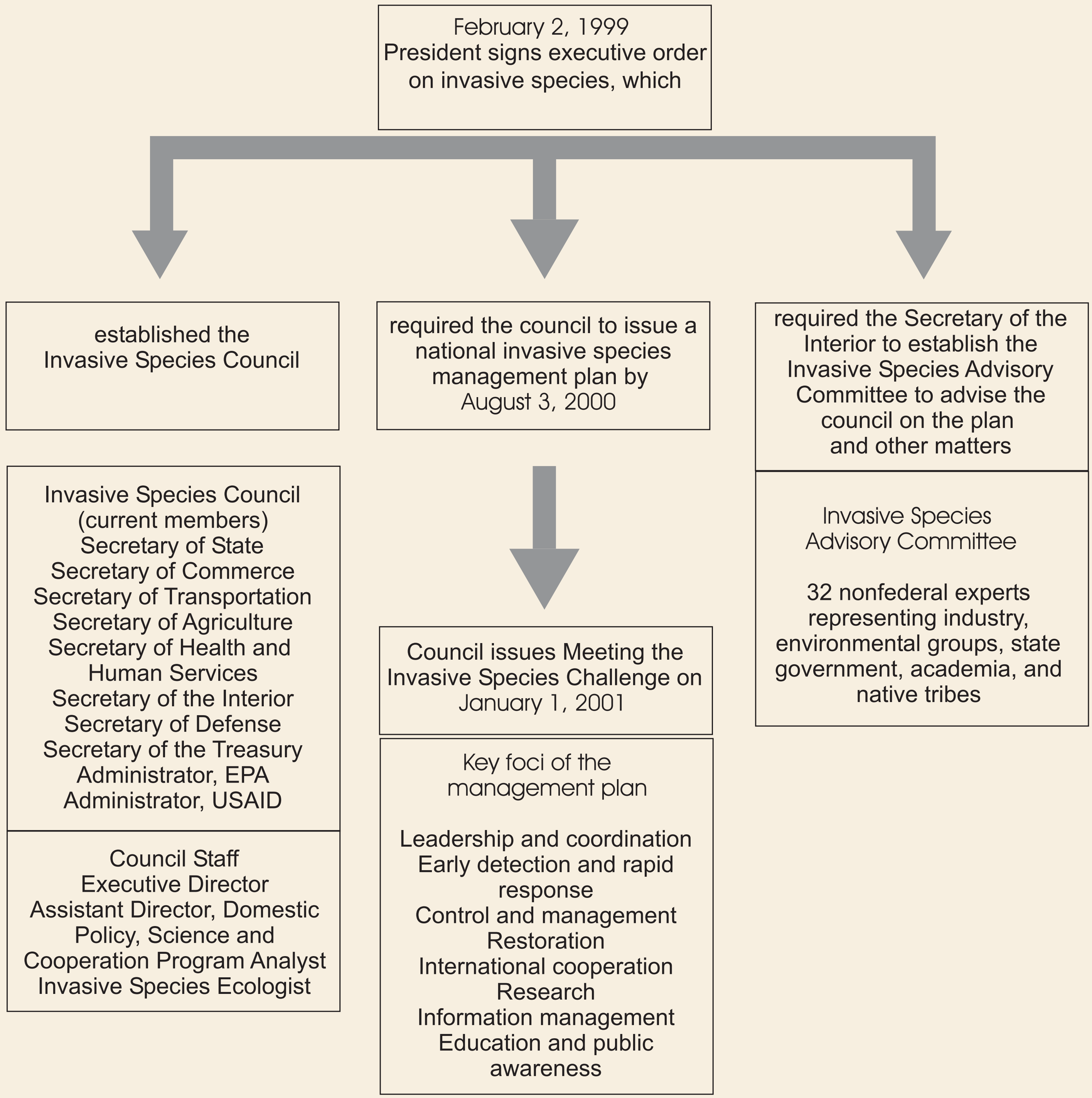
Who's managing all of this?

Management of invasive species occurs at the international, national and state levels. Internationally, the focus has been on ballast water, endangered species, agricultural pests and human health (see Appendix A). Terrestrial and freshwater species remain the dominant concerns at all levels, but concerns about saltwater species are increasing.

Within the United States, invasive species management is being addressed by coordinated efforts across multiple agencies (Figure 4). The coordination is to be conducted through the Invasive Species Council, a national management plan and the Invasive Species Advisory Committee (Figure 5). Further coordination regarding aquatic nuisance species and linking to states and regions occurs through the Aquatic Nuisance Species Task Force and its regional panels. In addition,

Source: Invasive Species: Federal and Selected State Funding to Address Harmful Nonnative Species, GAO/RCED-00-219 (Washington, D.C.: Aug. 24, 2000).

Figure 4. Key Federal departments and their responsibilities for invasive species.



Source: National Invasive Species Council

Figure 5. Formation and roles of the Invasive Species Council and Invasive Species Advisory Committee.

Box 9.

Incidences that illustrate a need for effective vector awareness and management tools.

1989 seaweed with bait

Seaweed used as packing for bait worms from Maine is discarded in San Francisco Bay. As a result, the carnivorous European shore crab (*Carcinus maenas*) and the Atlantic rocky shore snail (*Littorina saxatilis*) invade the Pacific Coast.

1992 illegal live imports

The Chinese mitten crab (*Eriocheir sinensis*) is discovered in San Francisco Bay. Illegally imported live animals from Asia are intercepted at California airports.

1998 historic battleship

To soak the hull in freshwater, the USS Missouri is moved into the Columbia River prior to heading for the Hawaiian Islands. However, the lower hull remains in saltwater, and as a result, the Mediterranean mussel (*Mytilus galloprovincialis*) establishes in Pearl Harbor and colonizes the ballast tanks of a submarine.

1998 mariculture

Atlantic salmon (*Salmo salar*) escape from farms in the Pacific Northwest.

2000 marina floats

Floats are towed at sea from New Jersey to Massachusetts even though they are encrusted with fouling organisms, including the Asian Crab (*Hemigrapsus sanguineus*).

2000 home aquarium

The Mediterranean green seaweed (*Caulerpa taxifolia*) is apparently released from a home aquarium into a lagoon near San Diego. It creates a well-established population and eradication efforts follow.

2000 live seafood

A hotel sushi bar releases live, Japanese freshwater crabs (*Geothelphusa dehaani*) into Lake Las Vegas in Nevada, and they are later found walking around.

2001 raw shellfish

New Jersey embargoes 6,000 cases of raw clams from China, which were labeled 'cooked.' Hepatitis A virus is found in the shellfish.

states are appointing people to deal with invasive species and developing management plans in concert with national efforts (see Appendix B).

Management plans at all levels typically recognize prevention or control of introductions as the key to success. Once a species establishes and spreads, eradication or control become far more costly and less likely. Surveillance for nonindigenous species and rapid removal before they establish and spread is the second best defense. Management plans also recognize the need for research, education and outreach. Gathering and disseminating better information can help us manage invasive species. For example, informed decision-makers should make better choices about large-scale, intentional introductions, and an informed public can modify their behavior to prevent small-scale, intentional or accidental introductions.

Along with others, the National Sea Grant College Program and its state programs contribute to management efforts (see Appendix C). For example, the National Sea Grant College Program awards grants for research and outreach related to invasive species. Partnerships among other Sea Grant College Programs, such as Alabama, Florida, Louisiana and Mississippi, coordinate efforts dealing with invasive species in their coastal and marine systems. Key projects include workshops to help formal and non-formal educators incorporate invasive species into their classroom activities.

Certainly, we can find times where our management of coastal and marine invasive species fails (Box 9). All of us can help improve future efforts (Box 10).

Box 10.

What can I do about introduced species in coastal and marine systems?

You can:

- never release aquarium species, bait, fish, water garden plants or other plants and animals into the wild
- remove attached plants and animals from boats, trailers, SCUBA gear, anchors and all other equipment
- drain water from boats, live wells and bilges before entering new areas
- only release ballast water as directed by the United States Coast Guard
- never use non-native species for bait

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Glossary

alien species. Any species that is not native to a given ecosystem, including seeds, eggs, spores, or other material capable of propagating the species.

ballast water. Water used to adjust the trim and stability of a vessel.

biocontrol. The release of one species in an effort to control another.

bioinvasions. Introductions assisted by humans and natural range expansions.

community. A group of populations that occupy the same area and interact.

cryptogenic species. A species that may be introduced but we cannot distinguish it from similar natural populations without genetic analyses.

ecosystem. Natural systems that produce and recycle more energy and other resources than they import.

ecosystem services. Things or activities that we value and would not have without a healthy ecosystem to support them.

endangered species. A species under threat of imminent extinction.

established. A nonindigenous species that produces self-sustaining populations or a species that is naturalized.

exotic species. A species that has been introduced into a country that does not contain any of its natural range.

extinction. The complete global disappearance of a species.

extirpation. The local disappearance of a species, as opposed to extinction.

fouling organism. Animals and plants, such as barnacles, mussels and seaweeds, that attach to human-made substrates, such as piers, navigation buoys and the bottoms of ships.

grazing. Feeding on plants.

hybridize. To interbreed.

indigenous species. A species that has not been introduced but rather historically occurred or currently occurs in an ecosystem.

intentional introduction. The purposeful import, introduction or transplant of a nonindigenous species into an area or ecosystem where it was not previously established.

interference competition. Interactions during the pursuit of resources, such as space, food or water, in which one species interferes with or harms another.

introduced invasive species. Species that undergo population explosions and cause harm after being transported to a new area by human actions or activities.

introduced species. A species whose presence in a given region can be traced to human actions or activities that dispersed it across natural geographic barriers or produced conditions favorable to its growth and spread.

introduction. The movement of an animal to an area outside its natural range through human activities.

invasion. The spread of a species to a new area due to natural causes or human introduction.

invasive species. A species that causes or is likely to cause harm to the economy, environment or human health.

native species. A synonym for indigenous species.

native invasive species. Species that get into modified habitats by their own means and then go through population explosions and cause harm.

naturalized. A synonym for established.

natural range. The area occupied by a species other than where it has been introduced.

nonindigenous species. A synonym for alien species.

non-invasive species. A nonindigenous species that does not spread but remains localized within its new environment.

non-native species. A synonym for alien species.

pathogen. A specific agent that causes a diseases, such as a bacterium or virus.

pathway. The route or geographic corridor for an invasion.

pest. Can be treated as a synonym for invasive species.

population. An interbreeding group of organisms.

predation. Feeding on animals.

scramble competition. Interactions during the pursuit of resources, such as space, food or water, in which one species captures the resources without interfering or harming another.

threatened species. Any species that is likely to become endangered within the foreseeable future throughout all or a significant portion of its range.

translocation. A synonym for introduction.

transplanted species. A species moved from its natural range to another area within the same country.

unintentional introduction. An introduction resulting from activities other than the purposeful or intentional movement of a species, including transport in ballast water or in water used to transport plants or animals for aquaculture or other purposes.

vector. A method of introduction.

Appendix A. International laws and conventions related to invasive species.

Agreement	Relevance	Web site
International Plant Protection Convention (IPPC)	prevent introduction and spread of pests affecting plants	http://www.fao.org/legal/treaties/004t-e.htm
Agreed Measures for the Conservation of Antarctic Fauna and Flora	require permits for introduction of nonindigenous plants and animals into the Antarctic Treaty Area	http://www.antarctica.ac.uk/About_Antarctica/Treaty/Flora_and_Fauna.html
The Convention on Wetlands (Ramsar Convention)	protect wetlands from various threats including invasive species	http://www.ramsar.org/index.html
Biological Weapons Convention (BWC)	prohibit development, production, stockpiling, acquisition or retention of microbial or other biological agents that are not for peaceful use	http://www.fas.harvard.edu/~hsp/biologic.html
Convention on International Trade in Endangered Species (CITES)	regulate invasive species not covered by other agreements	http://international.fws.gov/laws/citestxt.html
Convention on Migratory Species of Wild Animals	prevent, reduce or control factors that endanger any species, including introduced exotic species	http://www.cms.int/
Convention on the Conservation of Antarctic Marine Living Resources	prevent changes or minimize the risk of changes in the Antarctic marine ecosystem including the effects of alien species	http://sedac.ciesin.org/entri/texts/antarctic.marine.resources.1980.html
United Nations Convention on the Law of the Sea (UNCLOS)	prevent, reduce and control the intentional or accidental introduction of potentially harmful species to the marine environment	http://www.univie.ac.at/RI/KONTERM/intlaw/konterm/vrkon_en/html/doku/unclos.htm
Protocol to the Antarctic Treaty on Environmental Protection	require permits for introducing species to Antarctica	http://sedac.ciesin.org/entri/texts/antarctic.treaty.protocol.1991.html
Convention on Biological Diversity (CBD)	prevent introductions or control or eradicate alien or modified species that threaten ecosystems, habitats, species or human health	http://www.biodiv.org/
Framework Convention on Climate Change	stabilize and eventually reduce greenhouse gas concentrations that raise temperatures, change rainfall patterns and induce or exacerbate invasions	http://unfccc.int/
Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement)	protect animals or plants from pests and diseases	http://www.wto.org/english/tratop_e/sps_e/spsund_e.htm
Agreement concerning Cooperation in the Quarantine of Plants and their Protection against Pests and Diseases	apply quarantine to prevent the introduction of plant pests, diseases and weeds	http://sedac.ciesin.org/entri/texts/quarantine.of.plants.1959.html

Agreement	Relevance	Web site
Convention on the Law of Non-navigational Uses of International Watercourses	prevent the introduction of species into an international watercourse	http://www.un.org/law/ilc/texts/nnavfra.htm
Biosafety Protocol (Protocol to the CBD)	control transboundary movement of living, modified organisms	http://www.biodiv.org/biosafety/
European and Mediterranean Plant Protection Organization	prevent introduction and spread of pests and diseases of plants and animals	http://www.eppo.org
Protocol Concerning Specially Protected Areas Wildlife to the Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Area	prevent intentional or accidental introduction of harmful nonindigenous or genetically altered species into the Caribbean Region	http://www.cep.unep.org/pubs/legislation/spaw.html
North American Agreement on Environmental Cooperation	develop recommendations regarding harmful exotic species	http://www.cec.org
North American Free Trade Agreement (NAFTA)	require notice of intent to restrict imports	http://www.sice.oas.org/tradee.asp
Convention on Great Lakes Fisheries Between the United States and Canada	control and eradicate the non-native, highly invasive Atlantic sea lamprey from the Great Lakes	http://www.glfc.org/pubs/conv.htm
United Nations Conference on Environment and Development (UNCED)	control invasive species and their impacts	http://www.igc.org/habitat/agenda21/
World Trade Organization (WTO) – formerly GATT	require notice of intent to restrict imports	http://www.wto.org/wto/english/docs_e/legal_e/final_e.htm
International Maritime organization	deal with ballast water as a vector for invasive species	http://www.imo.org
United Nations Conference on Environment and Development (UNCED)	protect forests against invasive species	http://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm
Global Programme of Action for the Protection of the Marine Environment from Land-based Activities	recognize invasive species as an important threat	http://www.unep.org/unep/gpa/pol2a.htm
International Civil Aviation Organization (ICAO) Resolution	reduce risk of introductions	http://www.icao.int/

Appendix B. Experts on invasive species in the United States. (Source U.S. Fish and Wildlife Service; compiled November 2003).

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	Barbra Mullin State Weed Coordinator	Montana Department of Agriculture, Agriculture Science Division	P.O. Box 200201 Helena, MT 59620-0201	406-444-3140	406-444-7336	bmullin@state.mt.us
NE	Steve Schainost	Nebraska Game and Parks Commission	2200 N. 33rd Street Lincoln, NE 68503	402-471-5443	402-471-5528	schainost@ngpc.state.ne.us
NV	Anita Cook	Nevada Division of Wildlife	1100 Valley Road Reno, NV 89512	775-688-1532	775-688-1595	acook@govmil.state.nv.us
	Jon Sjoberg	Nevada Division of Wildlife	4747 Vegas Drive Las Vegas, NV 89108	702-486-5127	702-486-5133	
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	Amy Smagula Clean Lakes and Exotic Species Program Coordinator	New Hampshire Department of Environmental Services	6 Hazer Drive P.O. Box 95 Concord, NH 03302	603-271-2248	603-271-7894	asmagula@des.state.nh.us
NJ	Floyd Yoder Supervisor, Seed Certification and Control	New Jersey Department of Agriculture, Division of Plant Industry	P.O. Box 330 Trenton, NJ 08625	609-292-6075	609-292-4710	floyd.yoder@ag.state.nj.us
	Robert Cartica Coordinator	Office of Natural Lands Management	22 South Clinton Avenue P.O. Box 404 Trenton, NJ 08625	609-984-1015	609-984-1427	rcartica@dep.state.nj.us
	David Snyder Botanist	Office of Natural Lands Management	22 South Clinton Avenue P.O. Box 404 Trenton, NJ 08625	609-984-7849	609-984-1427	dsnyder@dep.state.nj.us
NM	Brian Lang	New Mexico Department of Game and Fish	1085-A Richards Avenue Santa Fe, NM 87505	505-476-8108	505-827-9956	blang@state.nm.us

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	Gerald A. Barnhart Assistant Director of Fish and Wildlife	New York Department of Environmental Conservation	625 Broadway Albany, NY 12233-4756	518-457-5691	518-457-0341	nydecdk@netsync.net
	William J. Culligan (alternate) Supervising Aquatic Biologist	New York State Department of Environmental Conservation, Lake Erie Fisheries Unit	178 Point Drive North Dunkirk, NY 14048-1031	716-366-0228	716-366-3743	nysdecdk@netsync.net
NC	Dean Horkavy	North Carolina Division of Water Resources	1611 Mail Service Center Raleigh, NC 27699-1611	919-715-5452	919-733-3558	dean.horkavy@ncmail.net
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OH	Gary Isbell Executive Admin., Fish Management and Research	Ohio Department of Natural Resources	1840 Belcher Drive, G Columbus, OH 43224	614-265-6345	614-262-1143	gary.isbell@dnr.state.oh.us
	Randy Sanders (alternate) Aquatic Nuisance Species Program Administrator, Fish Management and Research	Ohio Department of Natural Resources, Division of Wildlife	1840 Belcher Drive, G3 Columbus, OH 43224	614-265-6344	614-262-1143	randy.sanders@dnr.state.oh.us
OK	Jeff Boxrucker	Oklahoma Department of Wildlife Conservation	500 East Constellation Norman, OK 73072	405-325-7288		jboxrucker@aol.com
OR	Andrew Schaedel	Oregon Department of Environmental Quality	811 SW 6th Avenue Portland, OR 97204	503-229-6121	503-229-6957	schaedel.andrew.l@deq.state.or.us
	Mark Sytsma Aquatic Nuisance Species Coordinator	Portland State University, Center for Lakes and Reservoirs	1025 Harrison Street Portland, OR 97207-0751	503-725-3833	503-725-3888	sytsmam@pdx.edu
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	Leo Dunn	Pennsylvania Department of Agriculture, Bureau of Market Development	2301 North Cameron St. Room 311 Harrisburg, PA 17110	717-783-8462	717-787-5643	ledunn@state.pa.us
RI	Kevin R. Cute Marine Resource Specialist	Rhode Island Coastal Resource Management Council	4808 Tower Hill Road Wakefield, RI 02879	401-783-3370	401-783-3767	k_cute@crmc.state.ri.us
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TX	Bruce A. Moulton Program Specialist	Texas Natural Resources Conservation Commission	P.O. Box 13087 Austin, TX 78711-3087	512-239-4809	512-239-6195	bmoulton@tnrcc.state.tx.us
	Larry McKinney (alternate)	Texas Parks and Wildlife Department	4200 Smith School Road Austin, TX 78744	512-389-4636	512-389-4394	larry.mckinney@tpwd.state.tx.us
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VA	Tom Wilcox	Virginia Department of Game and Inland Fisheries	4010 West Broad Street Richmond, VA 23230	804-367-8998	804-367-2427	twilcox@dgif.state.va.us
WA	Scott Smith Aquatic Nuisance Species Coordinator	Washington Department of Fish and Wildlife	600 Capital Way North Olympia, WA 98501-1091	360-902-2724	360-902-3845	smithsss@dfw.wa.gov
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WY	Mike Stone Chief of Fisheries	Wyoming Game and Fish Department	5400 Bishop Boulevard Cheyenne, WY 82006	307-777-4559	307-777-4611	mstone@state.wy.us
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Appendix C. Sources of information on introduced or invasive species, their management, and their use in research and education.

Description	Source
Aquatic and marine species, all states	http://nas.er.usgs.gov http://invasions.si.edu/ http://www.anstaskforce.gov/ http://www.sgnis.org/
Marine species, New England only	http://massbay.mit.edu/exoticspecies
Aquatic species, Gulf of Mexico states	http://nis.gsmfc.org/
Aquatic species, California only	http://www.elkhornslough.org/invader.htm
Plants and insects, all states	http://www.invasivespecies.org
Plants, all states	http://invasives.eeb.uconn.edu
National Sea Grant College Program Invasive Species Clearinghouse	http://www.aquaticinvaders.org/nan_1d.cfm
National Invasive Species Council	http://www.invasivespecies.gov
National Invasive Species Council tool kit for managers	http://www.invasivespecies.gov/toolkit/main.shtml
National Biological Information Infrastructure federal and state resources	http://www.nbii.gov/geographic/us/state.html
National Biological Information Infrastructure best management practices	http://www.nbii.gov/datainfo/bestpractices
Guidelines for working with microorganisms	National Institutes of Health (NIH). 1968. Guidelines for Research Involving Recombinant DNA Molecules. Published in the Federal Register May 7, 1986 (51FR 16958-16961) with additional major actions published on August 24, 1987 (52F 31838); July 29, 1988 (53FR 28819); October 26, 1988 (53FR 43410); March 13, 1989 (54FR 10508); March 1, 1990 (55FR 7438); and August 11, 1987 (52FR 29800) with appendix P for plants and Q for animals. U.S. Department of Agriculture (USDA). 1984. Coordinated Framework for Regulation of Biotechnology. Published in the Federal Register December 31, 1984 (49FR 50856) and June 26, 1986 (51FR 23302+). U.S. Department of Agriculture (USDA). 1986. Advance Notice of Proposed USDA Guidelines for Biotechnology Research. Published in the Federal Register June 26, 1986 (51FR 23367-23393) and February 1, 1991 (56FR 4134-4149). U.S. Department of Agriculture (USDA). 1986. Introduction of Organisms and Products Altered or Produced Through Genetic Engineering Which are Plant Pests or for Which There is Reason to Believe are Plant Pests. Published in the Federal Register June 26, 1986 (51FR 23352-23366) and June 16, 1987 (52FR 22892-22915). Coulson, J. R., and R. S. Soper. 1989. Protocols for the Introduction of Biological Control Agents in the U.S. Chapter I, pages 2-35 In: Kahn, R. P. (ed.). Plant Protection and Quarantine. Volume III Special Topics. CRC Press, Inc., Boca Raton, Florida. U.S. Department of Agriculture (USDA). Office of Agricultural Biotechnology. 1988. USDA Guidelines for Research Outside the Laboratory Involving Biotechnology. Also Federal Register June 26, 1986 (51FR 23367-23313) and February 1, 1991 (56FR 4134-4149).

Description	Source
Guidelines for working with whole plants and animals	Jennings, D. P., and J. A. McCann. 1991. Recommended Protocol for Handling Nonindigenous Aquatic Species. National Fisheries Research Center, U.S. Fish and Wildlife Service, Gainesville, FL. 43-page manuscript. http://www2.mcgill.ca/biology/phytotron/ipm_responsibilities.htm
International guidelines for working with nonindigenous species	European Inland Fisheries Advisory Commission. 1988. Code of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms. FAO. EIFAC. Occasional paper No. 23. 52 pages. International Council for the Exploration of the Sea. 1982. Proposed Guidelines for Implementing the ICES Code of Practice Concerning Introduction and Transfer of Marine Species. 23-page manuscript.
Guidelines for working with pathogens	Anonymous. 1989. Operating Procedures for the Alma Quarantine Facility. Prepared for the Alma Research Station, Guelph, Ontario, Canada. 16 pages typewritten. Horner, R. W., and R. L. Eschenroder. 1991. Protocols to Minimize the Risk of Introducing Salmonid Disease Agents with Importation of Salmonid Fishes. Draft manuscript. 11 pages. Prepared for Great Lakes Fish Disease Control Committee. Pages 27-37. U.S. Department of Health and Human Services. 1984. Biosafety in Microbiological and Biomedical Laboratories. 1st Edition (March 1984). U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, Atlanta, Georgia 30333, and National Institutes of Health, Bethesda, Maryland 20892. An additional 17 references on laboratory disease and pathogen control methods can be found listed in the Federal Register, May 7, 1986 (51FR 16965).

Educational Materials on Marine Invasives

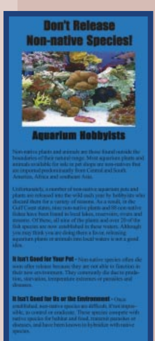
Preventing or controlling introductions is the best defense against invasive species. Florida Sea Grant and its partners provide these additional educational materials for coastal residents.

Can We Stop "Killer Algae" from Invading Florida?

Several species of *Caulerpa* grow in Florida, and the state has ideal conditions for an introduction of the now infamous invasive alga, *Caulerpa taxifolia,* which decimated habitats in the Mediterranean. Florida's coastal residents can help prevent an invasion of this killer algae by following a few simple measures outlined in this full-color, 2-page fact sheet. Contact Florida Sea Grant, (352) 392-2801, http://www.flseagrant.org. Single copies free, multiple copies have a charge. Request SGEF 155.

Are Native and Nonindigenous Seaweeds Overgrowing Florida's East Coast Reefs?

Scientists are concerned that extensive blooms of the non-native, green alga *Caulerpa brachypus* will spread on Florida's reefs unless the amount of nutrients entering the sea can be reduced. This 2-page, color fact sheet describes macroalgal blooms that have been found on Florida's east coast reefs and ways coastal residents can work to lower the nutrient loads that fuel them. Contact Florida Sea Grant, (352) 392-2801, http://www.flseagrant.org. Single copies free, multiple copies have a charge. Request SGEF 156.



Don't Release Non-Native Species — Water Gardeners/Aquarium Hobbyists

Most aquarium and water garden plants and animals sold in pet shops are non-natives imported predominantly from Central and South America, Africa, and Southeast Asia. This pair of two-sided, color rack cards explains the perils of releasing these non-native plants and animals into waterways and gives hobbyists safe alternatives for disposal. Contact Florida Sea Grant, (352) 392-2801, http://www.flseagrant.org. Single copies free, multiple copies have a charge.

Invasive Non-Native Plants Photo-Murals

Two large, fully laminated photo-murals depict 75 invasive non-native aquatic and terrestrial plants found in Florida and throughout the U.S. All plants are depicted in large, strikingly attractive color photographs. Free to Florida teachers and public agency trainers who request them in writing, on letterhead from APIRS Photo-Mural, Center for Aquatic and Invasive Plants, 7922 NW 71 ST, Gainesville, FL 32653. Copies can be purchased from the IFAS Extension Bookstore, (800) 226-1764, http://www.ifasbooks.ufl.edu.

Divers Alert! Dive Card

You can help prevent the spread of harmful marine invasives by reporting sightings of introduced species. This full-color, laminated card describes a variety of plants and animals that are already present in Florida waters or likely to invade soon. It also gives divers and boaters the Aquatic Nuisance Species toll free hotline and web site.

Green Mussel Alert Wallet Card

Invasive green mussels appeared in Florida in 1999. These bright green shellfish can grow densely on boats, buoys, and piers, and they may become pests that crowd out native oysters. This wallet card illustrates mussels and gives instructions for reporting their presence. Contact Florida Sea Grant, (352) 392-2801, http://www.flseagrant.org. Single copies free, multiple copies have a charge.

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