United States Environmental Protection Agency

NONINDIGENOUS SPECIES - AN EMERGING ISSUE FOR THE EPA

Volume 2: A LANDSCAPE IN TRANSITION: EFFECTS OF INVASIVE SPECIES ON ECOSYSTEMS, HUMAN HEALTH, AND EPA GOALS

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DISCLAIMER

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EXECUTIVE SUMMARY

Every day the United States is invaded by a host of nonindigenous species, also known as exotic, introduced, alien, or non-native species. A portion of these nonindigenous species becomes invasive species — the nonindigenous species resulting in ecological damage, human health risks, or economic losses. To help identify the key scientific issues related to invasive species, the EPA Regions and ORD held a series of Regional workshops followed by a National Workshops series of Regional and National. These workshops are summarized in Volume 1 of this report(U.S. EPA, 2001. *Nonindigenous Species — An Emerging Issue for EPA. Volume 1. Region/ORD Nonindigenous Species Workshop Reports)*. This document constitutes Volume 2 of the *Nonindigenous Species — An Emerging Issue for EPA* report. One goal of this document is to provide an overview of the types of impacts invasive species have on ecosystem services, human health, and economics. Another goal is to explore how invasive species can impact the implementation of EPA's goals and mandates, and how EPA's regulations relate to the management of invasive species. The major points are summarized below:

Extent of Invasion: Nearly every terrestrial, wetland, and aquatic ecosystem in the United States has been invaded by nonindigenous species — one estimate puts the number of nonindigenous species in United States at 50,000 species. These invasions are still occurring, and the invasion rate is accelerating in some ecosystems.

Economic Costs: Invasive species are having a pronounced effect on the U.S. economy. Agriculture is the most impacted ($71 billion/year). Costs to other segments of the economy, including tourism, fisheries, and water supply, total $67 billion/year.

Ecological Services: Invasive species are degrading a suite of ecosystems services, including, but not limited to: 1) agriculture; 2) forestry; 3) commercial and recreational fishing; 4) frequency of fire; 5) flood control; 6) municipal, industrial, and agricultural water supply; 7) boating and swimming; 8) climate change; and 9) culture preservation. Degradation of these services results in direct economic losses, costs to replace the services, and control costs. While more difficult to quantify, losses of these ecosystem functions also reduce the quality of life.

Pollutant Loadings and Dynamics: Terrestrial and wetland invasive species can dramatically alter the loadings of nutrients, clean sediments, and toxic pollutants into surface and estuarine waters. Invasive aquatic species, such as the zebra mussel, can alter the toxic effects and bioaccumulation of contaminants by altering pollutant fate and dynamics within water bodies.

Biodiversity and Endangered Species: Invasive species are the second most important cause for the listing of threatened and endangered species as well as being a major factor in the regional and global declines in biodiversity. One consequence of this loss of biotic diversity is the homogenization of the world's ecosystems. Another effect is the loss of ecosystem sustainability.

Exotic Diseases: Introductions of exotic diseases, such as the West Nile virus, are related to the breakdown of the same ecological, social, and economic barriers related to the introduction of other nonindigenous species. A potentially important vector for the distribution of water-borne pathogens, such as cholera, is the discharge of ballast water. Several of these exotic diseases have the potential of becoming serious regional or national public health threats, and their number and geographical extent are likely to increase with global climate change.

Pesticide Use and Exposure: A major portion of all pesticides are targeted for exotic weeds, insects, and mites. Presumably, a similar proportion of the ecological and human health effects resulting from pesticides mirrors this usage pattern. The percentage of pesticides targeted for exotic pests will increase with the continual introduction of new pests.

Executive Order on Invasive Species: An Executive Order on Invasive Species was authorized in 1999. The Order created the National Invasive Species Council, an interagency council of which the EPA is a member. The Invasive Species Management Plan, released in January 2001, lists 57 action items, of which 21 relate to the EPA.

GPRA Goals: Invasive species potentially affect nine of the ten GPRA Goals, with Goal 2 (Clean and Safe Waters) being the most affected. Other GPRA Objectives potentially affected include those relating to exposure to pesticides and persistent organic pollutants, remediation of contaminated sites, climate change, and reduction of transboundary threats. Failure to account for invasive species may result in non-attainment of certain GPRA Objectives.

Ballast Water Regulation: In January 1999, the EPA was petitioned to regulate all ballast water discharges under NPDES. The Agency has not yet responded to the petition. Regardless of EPA's decision, there is likely to be increased pressure to require mid-ocean ballast water exchange, and most likely ballast water treatment.

Wetland and Superfund Remediations: Constructed or remediated wetland and upland habitats are often invaded by invasive species, which can impair the reestablishment of desired ecosystem functions. The remediated sites can also serve as "hot spots" for the invasion of neighboring habitats. Legal issues regarding the extent to which Superfund sites have to be returned to their native state and who is responsible need to be addressed. Use of exotic plants for phytoremediation or erosion control is limited by the Executive Order, and to the extent possible, native alternatives need to be found.

Total Maximum Daily Loads (TMDLs): All waters impaired by pollutants must be listed, and States, Territories and authorized Tribes must establish TMDLs for these waters. Currently more than one-third of all the States have waters that are listed for invasive species. EPA believes that determination of whether a particular invasive species is a pollutant, requiring establishment of a TMDL, requires a case-by-case analysis. In the future, the Agency may reevaluate whether invasives such as noxious aquatic plants are pollutants for Clean Water Act purposes. Additionally, by altering erosion, runoff, and deposition processes, terrestrial, wetland, and aquatic invasive species can substantially alter pollutant loadings into surface and estuarine waters. Failure to account for these effects in TMDL models could result in substantial errors in calculating load allocations.

Role Of EPA in Managing Invasive Species: To date, EPA has had a relatively minor role in the management of invasive species, in part because of uncertainty over the interpretation of existing regulations. While legal and policy reviews are needed, possible roles for EPA include: 1) review of environmental impact statements under NEPA; 2) review of biocontrol agents under NEPA; 3) ballast water management under NPDES; 4) evaluation of invasive species impacts under ocean and inland dredge disposal regulations; 5) emergency registration of pesticides for invasive species under section 18 of FIFRA; 6) use of TMDLs on a case-by-case basis for waters that are impaired by invasive species; 7) early detection through monitoring programs; and 8) restoration of contaminated or disturbed habitats to native habitats under Superfund and other restoration programs.

Research Role for EPA: With its experience in evaluating ecological condition and in risk assessments, EPA brings unique skills to invasive species research. To focus the research, ORD needs to work with the Program Offices and Regions to identify the highest priority needs. Besides targeted invasive species research, much of the ongoing ecological research could incorporate invasive species as a stressor at little additional cost.

Stakeholders/Politics: There is growing public and political concern over invasive species; accordingly we anticipate there will be growing pressure from a suite of stakeholder groups for the EPA to take a more active role in researching and managing invasive species. Even more so than for pollutants, management of invasive species is complicated by opposing stakeholder values regarding control measures (e.g., use of pesticides) and over the relative benefits or harm of particular exotic species (e.g., exotic trout in western streams).

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I. INTRODUCTION

The ecosystems of the United States are being invaded by an unprecedented number of nonindigenous species. Nonindigenous species, also referred to as exotic, introduced or non-native species, are those species displaced from their historic range. Every major terrestrial, wetland, and aquatic ecosystem in the United States has been invaded to some extent, and in some habitats it is hard to find a native species. One estimate puts the total number of nonindigenous species in the United States at 50,000 species (Pimentel et al., 2000; http://www.news.cornell.edu/releases/Jan99/species_costs.html), and the number is increasing almost daily. Nonindigenous species invade through a wide variety of vectors - ballast water, agricultural and horticulture shipments, packing material and pallets, releases from the pet and live seafood trades, intentional releases by state agencies and the public, and as hitchhikers on boats, planes, trains, and automobiles.

As a general rule, approximately 10 percent of exotic species will become “invasive” or “nuisance” species, the nonindigenous species causing unacceptable ecological or economic damage or threatening human health. According to the Office of Technology Assessment (OTA, 1993; http://www.wws.princeton.edu/cgi-bin/byteserv.prl/~ota/disk1/1993/9325/9325.PDF) about 15 percent of the 4500 nonindigenous species they evaluated caused severe harm, close to the 10 percent rule. Based on the estimate of 50,000 nonindigenous species, the 10 percent rule suggests that there are approximately 5000 invasive species causing severe harm in the country. Some of these species are well known, such as the zebra mussel, kudzu vine, and many agricultural pests. Others are less well known, and in many cases the ecological, human health, and economic impacts of these species are only now beginning to be understood. There is also the question of the cumulative impact of the other 90 percent of the nonindigenous species; en masse —are they having deleterious ecological and economic effects that are not recognized on an individual species level?

One goal of this report is to put these threats into perspective by providing examples of the impacts from invasive species on ecosystem services, human health, and ecological condition. Another goal is to evaluate how invasive species affect the implementation of Agency mandates and goals. The last goal is to explore how existing environmental regulations relate to the management of invasive species. This discussion expands upon possibilities brought up at the National or Regional Nonindigenous Species Workshops and does not represent Agency policy or a legal review of the regulations.

This report is a direct outcome of the ORD/Region Nonindigenous Species Workshop held in Washington, DC on July 12 and 13, 2000. This national meeting was the culmination of a series of five Regional Nonindigenous Species Workshops held across the country to help identify high priority research needs related to nonindigenous species. Summaries of each of the Regional and National workshops are presented in Volume 1 of this report (U.S. EPA, 2001). An additional report was prepared for the Great Lakes (Glassner-Shwayder, 2000). Both the National and Regional workshops were held as part of the Office of Science Policy’s (ORD/OSP) “New Directions” program.

In gathering data for this document we relied both upon the published literature and web sources. In a rapidly evolving field like invasive species, web sources are often more up-to-date than the literature. In many cases, we give both the published and web sources, which allows readers without access to technical libraries to review pertinent information. In some cases, we used statistics directly from web sources, in which case the URL for the web page was cited. One peril with web sources is that they may either change or be deleted. Nonetheless, we believe web-based references will become an increasingly important mechanism to disseminate technical and policy information.

II. IMPACTS ON ECOSYSTEM GOODS AND SERVICES

Natural and managed ecosystems provide a number of goods and services that have direct economic benefits (e.g., agriculture, fisheries) or direct social benefits (e.g., recreation). This section provides examples of how nonindigenous species affect a variety of these goods and services. Impacts on the intangible benefits of natural systems (e.g., biodiversity) are discussed in "Section IV. Impacts on Ecological Condition".

II-1. U.S. Economy:

The full economic impacts of invasive species on the U.S. economy are only now beginning to be fully appreciated. The Office of Technology Assessment (OTA, 1993) estimated that just 79 of the thousands of nonindigenous species caused $97 billion in cumulative economic damage from 1906 to 1991. More recently, Pimentel and his colleagues (Pimentel et al. 2000; http://www.news.cornell.edu/releases/Jan99/species_costs.html) estimated the cost of invasive species to the U.S. economy at $138 billion per year, representing a hidden "tax" of about $500 per year to each U.S. citizen. These dollar figures translate into very real regional and local economic effects. A single weed, the leafy spurge (*Euphorbia esula*), results in $87.3 million in damage in North Dakota, the equivalent of about 1,000 jobs in a state with a population under 1 million (U.S. EPA, 2001).

Pimentel's analysis is the most comprehensive attempt at quantifying the economic consequences of invasive species, and their estimates for various economic impacts are used in this report in lieu of more specific figures. However, as impressive as these numbers are, they may underestimate the true cost as their analysis include only the direct "losses and damages" and "control costs" and not lost ecosystem services, such as water purification and aesthetic values (see Daily et al. 2000 and http://esa.sdsc.edu/daily.htm for discussion of ecosystem services). Moreover, the costs related to invasive species are increasing as nonindigenous species continue to spread at accelerating rates.

II-2. Agriculture:

Invasive weeds, insects, and pathogens have an enormous impact on American agriculture. Estimated costs from losses and control of exotic species are $27 billion/year for crop weeds, $13.5 billion/year for crop pests (mostly insects), $21.5 billion/year for crop pathogens, and $9 billion/year for livestock diseases (Pimentel et al., 2000; (http://www.news.cornell.edu/releases/Jan99/species_costs.html). This totals $71 billion/year, more than 50 percent of the estimated cost of invasive species in the United States. These agricultural costs are likely to increase with invasions of new exotic weeds and pests, most of which are likely to be "worse" than the existing pests (http://www.forages.css.orst.edu/Organizations/GLF/GLF8.html). Moreover, these economic losses do not include the economic or social costs associated with the human health impacts resulting from pesticides used on invasive pests (see "V-16. Pesticide Use and Pollution Prevention").

II-3. Pollination:

The introduced European honeybee has been the dominant pollinator for a number of fruit and vegetable crops (e.g., apples, cucumbers) worth about $10 billion dollars per year. However since the 1980s, exotic varroa and tracheal mites have decimated honeybee populations — wild populations have declined by about 90 percent and the number of cultured bee colonies has decreased by about 50 percent. An additional threat is the Africanized or "killer" bee, which either out competes or hybridizes with the European honeybee. Presumably, crop production will decrease as a result of reduced pollination from wild bee populations and/or costs of maintaining sufficient pollinators will increase. Additionally, beekeepers will suffer losses estimated at $29 - $58 million per year (http://agnews.tamu.edu/bees/). This example, in which a beneficial nonindigenous species is harmed by an invasive pest, illustrates some of the complexities inherent in managing nonindigenous species.

II-4. Commercial Fishing and Aquaculture:

Invasive species can have major impacts on commercial fish and shellfish populations, even to the point of the collapse of entire fisheries. An example is the American comb jelly, *Mnemiopsus leidyi*, which was introduced into the Black and Azov Seas in the 1980s (Harbison and Volovik, 1993). Without major predators, the population of this jellyfish-like invertebrate exploded, reducing native fish populations both by competing with larval fish for planktonic prey and by feeding upon fish eggs and larvae. In less than a decade, the anchovy catch fell from about 500,000 to 100,000 tons. *Mnemiopsus* has spread into the Mediterranean potentially threatening additional fisheries. Ominously, a basketball-sized Australian jellyfish, *Phyllorhiza punctata,* recently invaded the Gulf of Mexico; in some areas this jellyfish was so common that a "person could use them as stepping stones" (http://nas.er.usgs.gov/coelenterates/phyllorhiza.htm). It remains to be seen whether this particular exotic species will have a measurable impact on Gulf fisheries, but the *Mnemiopsus* example demonstrates that a single invasive predator/competitor can devastate a fisheries.

Introduced diseases can also devastate fisheries, as with the eastern oyster *Crassostrea virginica* that was a dominant species in eastern U.S. estuaries. Large scale oyster mortalities associated with infections of the protozoan *Haplosporidium nelsoni* (MSX) were first observed in Delaware Bay in 1957 (Haskin et al., 1966) and in the lower Chesapeake Bay in 1959 (Andrews, 1980). Within two years, more than 90 percent of the oysters in high salinity areas of the two bays were killed (Andrews, 1980). DNA analyses indicate that *H. nelsoni* was introduced from California or Asia and probably introduced with sanctioned plantings of the Japanese oyster *C. gigas* (Barber, 1997) or with ballast water. The continuing presence of *Haplosporidia* has prevented oyster recovery in the lower Chesapeake Bay and has limited development of oyster aquaculture.

Besides diseases, harmful algal blooms (HABs) of toxic phytoplankton can render shellfish unsafe for human consumption. The frequency and severity of HABs have increased both nationally and internationally (http://www.cop.noaa.gov/pubs/das10.html) and "seeding"of toxic dinoflagellates through ballast water discharges is considered as one contributing cause. For example, ballast water discharges are thought to cause toxic blooms of dinoflagellate *Gymnodinium catenatum* that are responsible for the periodic closure of Australian shellfish beds (http://www.environment.gov.au/marine/information/reports/somer/somer_annex1/som_ann8.html).

II-5. Recreation - Fishing:

As with commercial fisheries, invasive species impact recreational fish populations through predation, competition, diseases, and habitat alteration. One especially destructive pathogen is whirling disease (*Myxobolus cerebralis*). This pathogen was introduced into North America from Europe in the 1950s and has spread through the western states, including Yellowstone National Park. Whirling disease infects salmonids and is particularly damaging to rainbow trout; the rainbow trout population in the upper Madison River has declined from 3,300 to 300 fish per mile (U.S. EPA, 2001). To avoid infections of whirling disease from river water, many hatcheries have implemented extensive sterilization procedures and/or modifications to use groundwater. Despite spending $12 million since 1997 to upgrade state hatcheries, no stocked trout were released in Colorado in 2000 because of continued threat of infections (http://www.whirling-disease.org/whirling/nostockco.html). As discussed in Section "V-6. TMDLs", under certain cases hatcheries may be considered as point sources under an exotic disease TMDL.

An issue illustrating the conflicting views of different stakeholder groups towards nonindigenous species is the controversy over stocking non-native fish. Stocked fishes constitute a major portion of inland fishing in many states. Stocked fish account for 80 percent of the freshwater fishing in Washington State and generate $725 million dollars (http://www.nwr.noaa.gov/nnative/proceed/zook2.pdf). However, there is growing evidence that stocked fish result in a number of adverse ecological effects. At an ecosystem level, "introduced fish", many of which were stocked, impacted more highland stream miles than any other stressor in EMAP's Mid-Atlantic Integrated Assessment (MAIA) survey (http://www.epa.gov/emap/maia/html/rabrief/slide14.html). At a population level, a well-documented example is the decline in native trout populations due to predation by the introduced brown trout (http://www.afsifs.vt.edu/afspos.html). As discussed in "Section V-15. Ecological Risk Assessment", one of the complexities of managing nonindigenous species is that any particular non-native species may have both desirable and undesirable characteristics.

II-6. Recreation - Boating and Swimming:

Boating and swimming are made virtually impossible in many lakes by thick mats of floating (e.g., water hyacinth [*Eichornia crassipes*]) or rooted (e.g., Eurasian watermilfoil [*Myriophyllum spicatum*]) aquatic weeds (see http://www.ecy.wa.gov/programs/wq/plants/weeds for description of aquatic weeds). Decaying mats of these plants can also make beaches unusable. Approximately $100 million is spent annually to control aquatic weeds in the United States (Pimentel et al. 2000; (http://www.news.cornell.edu/releases/Jan99/species_costs.html) and in many cases, these programs are considered successful if they can simply "hold the line". Even with an expenditure of $50 million during the 1980s, the percentage of Florida waters invaded by hydrilla (*Hydrilla verticillata*) increased from 37 percent to 41 percent (http://www.ecy.wa.gov/programs/wq/plants/weeds/aqua001.html). Generally, aquatic weeds are a greater problem in inland waters than in coastal areas, though dense strands of the invasive smooth cord grass, *Spartina alterniflora*, limit recreational use of intertidal areas on the West coast.

II-7. Recreation - Tourism:

Invasions of non-native weeds can change the entire character of public lands. As reported in the Governor's Idaho Weed Summit (http://www.blm.gov/weeds/BOISUMMI.WPD.html), the Nature Conservancy's Altamount Prairie, South Dakota is no longer managed as a native prairie. Even when invasives do not "take over" an ecosystem, they can reduce its recreational value. Accessibility to park lands and trails can be limited by prickly weeds, such as yellow star thistle (*Centaurea solstitialis*), while other invasives can reduce the populations of recreationally important species, such as the impact of whirling disease on trout. A more subtle response is the "emotional" or "spiritual" loss resulting from the degradation of native ecosystems. This societal value is reflected in the National Park Service policy of actively managing exotic weeds, which it considers "one of the most serious threats that parks face" (http://www1.nature.nps.gov/wv/exotics.htm).

These reductions in recreational value translate into economic losses as tourists either go to less invaded areas or find non-wilderness forms of recreation. For example, the leafy spurge (*Euphorbia esula*) has resulted in a loss of $2.9 million dollars in recreational expenditures in North Dakota alone (Wallace et al., 1992).

II-8. Municipal, Industrial and Agricultural Water Supply:

Aquatic nuisance species, in particular non-native bivalves and aquatic weeds, can disrupt municipal, industrial, and agricultural water supplies. One of the main economic impacts of zebra mussels (*Dreissena polymorpha*) is clogging the intakes for water treatment and power plants. Left unchecked, zebra mussels can form mats up to eight inches thick. Another invasive bivalve, the freshwater clam *Corbicula fluminea*, impedes water flow through irrigation channels by forming shell reefs. The invasive Eurasian watermilfoil impacts power generation by clogging intake pipes (http://www.ecy.wa.gov/programs/wq/plants/weeds/aqua004.html) Estimates of the costs to water infrastructure systems vary widely. Khalanski (1997 in Pimentel et al, 2000; (http://www.news.cornell.edu/releases/Jan99/species_costs.html) estimated a cost of $5 billion per year in damage and control by 2000 for zebra mussels. In comparison, a survey of facilities across the country reported a cost of $69 million for zebra mussels (in Glassner-Shwayder, 2000).

Whatever the reasons for these differences, costs associated with the fouling of intake pipes and irrigation channels are likely to increase as existing invasive species expand their distribution and with the introduction of new aquatic nuisance species. An example of a new threat is the Asian green mussel (*Perna viridis*) that was recently discovered in electrical utility intake pipes in Tampa Bay (U.S. EPA, 2001). Another recent invader is the mitten crab (*Eriocheir sinensis*) that has been spreading through San Francisco Bay into the Sacramento River since the early 1990s (http://www.delta.dfg.ca.gov/mittencrab/life_hist.html). By burrowing into stream banks, this Asiatic crab weakens the levees supplying water to California's Central Valley agriculture while masses of migrating crabs clog fish diversion screens.

II-9. Forests and Timber Production:

About 360 nonindigenous insect species are found in U.S. forests, of which a third are serious pests (Liebold et al., 1995). The balsam wooly adelgid (*Adelges piceae*), one of The Nature Conservancy's "Least Wanted" alien species (http://consci.tnc.org/library/pubs/dd/toc.html), has destroyed three-quarters of the spruce-fir forests in the southern Appalachians. Another destructive pest is the gypsy moth (*Lymantria dispar*), which defoliates oaks and other hardwoods in the Northeast. In total, invasive insects result in a $2.1 billion annual loss in timber production (Pimentel et al 2000; http://www.news.cornell.edu/releases/Jan99/species_costs.html). Forest associated losses are likely to increase substantially if the recently introduced Asian long-horned beetle (*Anoplophora glabripennis*) becomes established. "Eventually it [Asian long-horn beetle] could eat its way through the 42 million acres of forests from Maine to Minnesota that are dominated by maple trees, forever changing the nation's landscape" (http://www.naplesnews.com/today/editorial/d306758a.htm).

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Forests are also vulnerable to introduced pathogens, which result in an additional $2.1 billion annual loss according to Pimentel. To date, the most damaging exotic disease has been the Chestnut blight, which dramatically changed the landscape of eastern forests in the early 1900s.

II-10. Hydrologic and Sediment-Transport Related Services:

High densities of invasive weeds and animals can alter basic geological processes, including runoff, erosion, sediment deposition, and groundwater recharge. In turn, these geological changes can impact water quality, water availability, susceptibility to flooding, and sustainability of wetland habitats. For clarity, the examples below are divided into different geological processes; in reality, they are usually coupled.

10-A. Stream Flow and Water Table:

Excess transpiration by exotic weeds can reduce surface runoff, groundwater storage, and wetland habitats. Salt cedar (*Tamarix* spp), a deep-rooted shrub common in riparian areas throughout the arid west, consumes 10 to 20 times the water used by native species. With its high water use, *Tamarix* can draw down the water table until streams and springs dry up (http://www.earlham.edu/~biol/desert/invasive.htm). The Australian melaleuca (*Melaleuca quinquernervia*) was intentionally dispersed to drain wetlands. Melaleuca now threatens wetlands throughout Southern Florida, including hundreds of thousands of acres in the Everglades (http://aquat1.ifas.ufl.edu/mcplnt2a.html).

10-B. Runoff and Erosion:

Erosion and runoff increases when native prairie grasses with fibrous root systems are replaced with exotic weeds with taproots. For example, runoff increased by about 50 percent and sediment erosion doubled when native bunch grasses were replaced by spotted knapweed (*Centaurea maculosa*) (Lacey et al., 1989; (http://www.blm.gov/weeds/BOISUMMI.WPD.html). In turn, the increased erosion resulted in higher stream temperatures and degraded fish habitat. Another study estimated spotted knapweed increased soil erosion by 18 tons per 500 acres during a single rainstorm (Duncan, 1997 in Westbrooks, 1998). By stripping the vegetation and rooting in the soil, invasive animals, such as feral pigs, goats, and burrows, can also dramatically increase erosion

Exotic plants can also reduce erosion, in particular by species that form dense covers or with extensive root systems. In some cases, such as with kudzu vine (*Pueraria montana* var. *lobata*), non-native species that were deliberately introduced to stabilize the soil have proven invasive. Non-native grasses are still frequently used in erosion control, though there use will be limited under the Executive Order ("V-1. Executive Order on Invasive Species"). Erosion can also be reduced indirectly when invasions of unpalatable weeds, such as yellow star thistle, reduce grazing pressure on pastures and rangelands.

10-C. Sediment Deposition:

Dense stands of aquatic and wetland plants act as sediment traps and invasions of such species can change the sediment dynamics in surface waters and estuaries. A freshwater example is the giant reed, Arundo (*Arundo donax*), which can reduce stream width and depth, and in some cases impede stream navigation (http://ceres.ca.gov//tadn/arundoWW.html). An estuarine example is the Atlantic smooth cord grass (*Spartina alterniflora*) (http://www.willapabay.org/~coastal/nospartina), which has greatly enhanced sedimentation rates in invaded West coast estuaries. Without control measures, such as aerial spraying of Rodeo, up to half of Willapa Bay's intertidal flats will be converted to elevated *Spartina* salt marsh over the next 20 years (Wolf, 1993). This conversion to elevated marsh is biologically equivalent to habitat loss from diking, and the immediate impacts include loss of commercial oyster growing grounds and habitat for migrating birds using the Pacific Flyway. Another concern is increased flooding resulting from the reduction in water holding capacity in areas invaded by *Spartina*.

Invasive filter-feeding bivalves also enhance sedimentation in lakes (e.g., zebra mussels) and estuaries (e.g., *Potamocorbula amurensis*) by actively stripping particles from the water column and depositing them as feces or pseudofeces. A simulation study of Saginaw Bay (Endicott et al., 1998) predicted that zebra mussels increased the flux of particles and contaminants from the water column to the sediment by seven-fold. Zebra mussels have been so effective at removing water-borne particles in some areas that they have noticeably increased water clarity (see "V-8. Ambient Water Quality and Pollutant Dynamics").

10-D. Nutrient Fluxes:

Increases in runoff resulting from invasive weeds increase nutrient fluxes into surface and estuarine waters. Presumably, the increases in nutrient inputs are directly related to the increase in runoff and erosion, which as mentioned above can increase by 50 percent to 100 percent. Additionally, invasive weeds can alter nutrient processes within the soil. An example is cheatgrass (*Bromus tectorum*). This innocuous looking grass introduced from Eurasia to Washington in the 1890s quickly spread throughout arid areas of the west to become a dominant grassland plant in Washington, Nevada, Utah, and Idaho. In comparison to the native grasses, cheatgrass grows in thick blankets that shade out the nitrogen-fixing microbiotic soil crusts, reducing nitrogen inputs. Other invasive weeds increase soil nitrogen, such as the Atlantic shrub, *Mycrica fava,* that has invaded the nitrogen-poor volcanic soils of Hawaii. *Mycrica*, a nitrogen fixer, adds nitrogen 90 times faster than the native flora, promoting invasion by other nonindigenous plants (Mack et al., 2000; http://esa.sdsc.edu/issues5.htm).

In addition to terrestrial weeds altering nutrient loadings to water bodies, aquatic weeds can change nutrient dynamics within water bodies. Decomposition of Eurasian watermilfoil during the fall increases loadings of phosphorus and nitrogen to the water column (http://www.ecy.wa.gov/programs/wq/plants/weeds/aqua004.html). In the tidal freshwater portions of Chesapeake Bay, *Hydrilla verticillata* sequesters nitrogen and phosphorous in its tissues during the growing season (http://chesapeake.org/pubs/procs/stavstev.html). In the Susquehanna Flats *Hydrilla* was a relatively minor component of the nutrient budget, but in the Potomac River *Hydrilla* sequestered between 2.5 percent and 40 percent of the annual point-source inputs of nitrogen and phosphorus during the summer growing season (Stevenson et al., 1989 in (http://chesapeake.org/pubs/procs/stavstev.html). These nutrients are then released in the autumn when the plants die back. Because nutrients are sequestered during the primary growing season and released in the fall, it was suggested that *Hydrilla* might "function in helping to suppress summer algal blooms and improving water quality."

II-11. Pollution Sequestration and Transformation:

Aquatic nuisance species can alter the sequestration (e.g., burial), degradation, and transformation of toxic pollutants, and hence the bioavailability of these pollutants. Enhanced sedimentation resulting from invasions of exotic wetland plants and filter-feeding bivalves ("II-10. Hydrologic and Sediment-Transport Related Services") removes sediment-associated contaminants from the water column and deposits them into the sediment. Deposition reduces exposure to water-column organisms and promotes long-term burial of pollutants. However, by concentrating the pollutants in the sediments, there is an increased likelihood of sediment toxicity and/or bioaccumulation by the benthos and subsequent trophic transport to their predators. Whether these biologically mediated processes increase or decrease toxic effects depends upon site and pollutant characteristics. Aquatic nuisance species can also alter pollutant bioavailability by altering trophic structure as discussed in section "V-8. Ambient Water Quality and Pollutant Dynamics".

II-12. Fires:

Fire frequency and intensity increases when fire-adapted weeds replace native flora. In the lower Colorado River flood plain, only 2 percent of the area with native flora burned between 1981 and 1992 versus 35 percent of the area invaded by salt cedar (*Tamarix* spp.) (Wiesenborn, 1996). The frequency of fire in the rangeland in the Great Basin increased from once every 60-110 years to every 3-5 years after the invasion of cheatgrass (*Bromus tectorum*) (Whisenant, 1990). Besides the ecological impacts, the increased fire frequency threatens human life and property. This threat is greatest in rural areas in the West, but even suburban areas can experience increased risk. The proliferation of the exotic eucalyptus tree (*Eucalyptus globulus*) with its high resin content contributed to the intensity of the 1991 Oakland, California fire that burned almost 3,000 dwellings (http://www.firewise.org/pubs/theOaklandBerkeleyHillsFire/).

II-13. Climate Change:

By reducing plant coverage and altering water cycles, overgrazing by domestic livestock, most of which are exotic, can contribute to climate changes on a regional scale. The desertification of Sub-Saharan Africa is the most dramatic example of such changes (http://pubs.usgs.gov/gip/deserts/desertification). Another large-scale alteration is the burning of substantial portions of the Amazonian forests and their replacement by African grasses (Mack et al., 2000; and http://esa.sdsc.edu/issues5.htm). Conversion of tropical forests to grasslands sequesters less carbon and increases carbon dioxide inputs into the atmosphere. In addition to these deliberate introductions, fundamental changes in plant communities due to invasive weeds, such as is occurring over much of the arid West, may also change carbon dioxide inputs into the atmosphere. Mack and his colleagues offer the following warning, “Our best estimate is that, left unchecked, the current pace and extent of invasions will influence other agents of global change — including the alteration of greenhouse gases in the atmosphere — in an unpredictable but profound manner.”

The converse is also true — alterations in global climate will influence invasive species. Native ecosystems stressed by climate change are likely to be more susceptible to invasions. Climate change is likely to have its greatest effect on promoting invasive species at the southern and northern edges or boundaries of ecosystem types. Besides being more susceptible to invasion, the increase in temperature will increase the number of sub-tropical and tropical invaders. As mentioned below, this may include tropical diseases and disease vectors previously rare in the continental United States (see “III-1. Human Health - Direct Risks”).

II-14. Structural Damage:

The introduced Formosan termite (*Coptotermes formosanus*) represents a substantial threat to the wooden buildings in nine southern states, California, and Hawaii (http://www.ars.usda.gov/is/fullstop/). Besides consuming wood nine times faster than native termites, the Formosan termite consumes live trees and can penetrate plaster and asphalt. This single exotic pest costs about $1 billion per year in damage and control costs. In New Orleans this single pest has caused more damage than hurricanes and floods combined over the last 10 years.

II-15. Cultural Preservation:

Invasive species threaten our cultural legacy. Historic buildings, for instance, are threatened by exotic wood-boring pests; a speaker at the National Nonindigenous Species Workshop (U.S. EPA, 2001) stated that the wooden buildings in New Orleans’ French Quarter could “disappear” in twenty years due to the Formosan termite. Formosan termites also infest a third of New Orleans’ historic live oaks. Underwater historical relics are also at risk. Zebra mussels threaten to encrust historic sunken ships throughout the Northeast and Canada, including Benedict Arnold’s ship in Lake Champlain. In addition, zebra mussels produce an anaerobic microenvironment promoting sulfur-reducing bacteria that disintegrate the iron spikes used in Revolutionary War ship hulls.

Another type of cultural loss is the decline in native plants of cultural significance to Native American Tribes. Many of these culturally important native plants decline due to the spread of invasive plants such as spotted knapweed and sulfur cinquefoil (*Potentilla recta*) (http://www.blm.gov/weeds/BOISUMMI.WPD.html).

III. IMPACTS ON HUMAN HEALTH

Invasive species threaten human health as well as ecological and agricultural systems. One type of health risk is direct, the introduction of exotic diseases. Introduction of these diseases results from the breakdown of the same economic, ecological, and social barriers that allow the spread of other nonindigenous species. In many cases, effective control of exotic diseases will require an integration of invasion biology and the public health community, which to date have not been well coordinated. The other type of risk is indirect, resulting from exposure to the pesticides used to control exotic pests.

III-1. Human Health - Direct Risks:

The list of invasive pests and diseases posing a human health risk reads like a cast of characters from a Steven King novel — fire ants, killer bees, brown tree snake, Brazilian pepper, West Nile virus, Lyme disease, influenza, and acquired immunodeficiency syndrome (AIDS). Even excluding AIDS, exotic diseases represent a national threat; under the correct conditions several of these diseases have the potential to infect thousands of individuals. The increasing globalization of the world increases the probability of the introduction of diseases previously unknown in this country. The West Nile virus was first reported in New York in 1999 and has since has been detected from Vermont to North Carolina, resulting in at least 18 deaths. Maps displaying the spread of the West Nile virus can be found on the USGS National Atlas (http://nationalatlas.gov/natlas/natlasstart.asp). Since most of the exotic diseases are tropical, global climate change is likely to result in a northward expansion of the areas at risk (http://www.jrc.es/iptsreport/vol13/english/Lif1E136.htm and http://www.greenpeace.org/~climate/database/records/zgpz0749.html).

The dispersal of water-borne diseases through ballast water discharges is of particular relevance to the EPA. In 1991, a Latin American epidemic strain of *Vibrio cholerae* was found in the ballast water of a ship in Mobile, Alabama (McCarthy and Khambaty, 1994). A public health advisory warning about the risks of eating raw seafood was issued when this strain was also found in fish and shellfish (http://nas.er.usgs.gov/publications/ballast.htm). More recently, a virulent Asian strain of *Vibrio parahaemolyticus* has been detected in U.S. coastal waters, raising the possibility of ballast water transport (http://www.wisc.edu/fri/nonvibrio.htm). The World Health Organization reported that ballast water discharge was the likely mechanism leading to the "introduction of cholera for the first time this century into Latin America in 1991" (http://www.who.int/inf-fs/en/fact124.html). While further studies are needed to conclusively establish the role of ballast water, the available evidence suggests that ballast water discharges are an unregulated source of water-borne pathogens into coastal and estuarine waters. Also, as mentioned above ("II-4. Commercial Fishing and Aquaculture"), ballast water discharges may increase the incidence of harmful algal blooms (HAB), which can result in paralytic shellfish poisoning (PSP) when contaminated shellfish are consumed.

By acting as disease vectors or hosts, exotic animals can promote the spread of both exotic and native diseases. The Asian tiger mosquito (*Aedes albopictus*), introduced into Houston in 1985 and now present in at least 26 states, is a potential vector for equine encephalitis, Dengue virus, and yellow fever (http://www.cdc.gov/ncidod/dvbid/arbor/albopic_new.htm). The Asian tiger mosquito is more likely to spread these diseases than are native mosquitos because it attacks more hosts and bites during the day. The Asian mitten crab (*Eriocheir sinensis*) was banned from importation into California in 1987 in part because it is a host for an Oriental lung fluke.

Besides diseases, several invasive pests, such as fire ants and poisonous plants, represent a direct human health threat. These exotic pests can be important on a regional scale though they do not pose the level of threat as the exotic diseases.

III-2. Human Health - Pesticide Exposure:

A substantial proportion of all pesticides used in agriculture are used to manage exotic weeds, insects, and pathogens (see "V-16. Pesticide Use and Pollution Prevention"). Presumably, a corresponding portion of all agricultural-related pesticide exposures and health risks result from exposure to pesticides used to manage exotic pests.

A different social/political milieu is the use of pesticides in urban and suburban settings. In 1997 there was a public outcry after 1 million people were exposed to malathion in the Tampa area in an effort to control the Medfly (*Ceratitus capitata*). Substantial portions of New York City and the outlying suburbs were subjected to aerial and ground spraying of malathion in 1999 with the discovery of the West Nile virus. Again, there was considerable public concern and some environmental groups blamed the 1999 die-off of lobster in Long Island Sound on the malathion (http://earthfiles.com/earth111.htm). The West Nile virus was discovered again in 2000, and New York initiated a control program using Anvil, a pyrethroid-based pesticide. The number of urban-suburban control programs is likely to increase with the continued introduction of exotic diseases and vectors. These programs differ from agricultural programs in the number of people exposed, greater potential for exposure of sensitive groups (e.g., children, asthmatics), the public's low level of awareness about pesticide risks and how to minimize exposure, and a lower acceptance of pesticide exposure than that in agricultural communities.

IV. IMPACTS ON ECOLOGICAL CONDITION

The ecological attributes addressed in this section represent aesthetic, ethical, or spiritual values to a substantial portion of the public (see Principe, 1995 for list of ecological values). For these stakeholders, the ecological attributes are important in themselves and not for their market benefits (e.g., ecotourism) or potential services (e.g., fire control). However, it is difficult to quantify how much of a deviation from "reference" or "natural" conditions in these attributes is acceptable. While the public supports "biodiversity" in principle, most people are unlikely to care much about a reduction in the number of microbial species. In contrast, the public will react vigorously to the extinction of a single species of songbird or marine mammal. It is beyond the scope of this report to address the socio-cultural aspects of invasions other than to note that there is a range in societal concerns regarding these ecological attributes. The public's specific reaction depends on a suite of factors including whether "charismatic" species are impacted, the number of species affected, size of the area impacted, and whether the nonindigenous species are "desirable" to certain stakeholders.

IV-1. Biodiversity:

Alterations to biodiversity are perhaps the most fundamental ecological impact of invasive species. A single invasive species can have devastating effects on local/regional species richness. The Nile perch (*Lates niloticus*) was introduced into Lake Victoria, the world's largest tropical lake, in1954 for fisheries development. Lake Victoria was home to 300 to 400 species of cichlid fish species, about 5 percent of the world's freshwater species (http://www.fao.org/waicent/faoinfo/fishery/statist/fisoft/dias/pape_nil.htm, http://www.acts.or.ke). By the 1980's about half of these unique cichlid species were driven to extinction due to predation by the Nile perch. The decline in the native algal-eating cichlids allowed massive blooms of undesirable algae, collapse of local subsistence fishing, and increased unemployment especially among women ("Report Of The Consultative Session On Lake Victoria Fisheries" available at http://www.acts.or.ke). Yet even with these impacts there are several stakeholders, in particular sports fishermen and fish exporters, who benefit from Nile perch (http://www.fishingafrica.co.za/articlegb598.html).

In the United States, the relative impact of invasive species on biodiversity can be ascertained from studies of the species listed under the Endangered Species Act. Wilcove et al (1998; http://www.fguardians.org/threats.html) concluded that 49 percent of the endangered or imperiled species of plants and animals were threatened by invasive species, second only to habitat loss. In an evaluation of 69 fish species listed under the Endangered Species Act, invasive species were cited in 70 percent of the listings, again only second to habitat degradation (Lassuy, 1995, http://www.nwr.noaa.gov/nnative/proceed/lassuy1.pdf).

Changes in the total number of species on the earth can be considered the ultimate metric of human impacts on ecological condition. Ominously, the modern species extinction rate is among the greatest in the earth's history (Wilson, 1988; Pimm and Lawton, 1998), and invasive species are one of the most important factors in this global loss of biological richness. In a study of global vertebrate extinctions, Cox (1993; http://biology.usgs.gov/s+t/SNT/noframe/ns112.htm) found that invasive species were responsible for 109 extinctions compared to 73 resulting from habitat disruption. Over the last 100 years, 3 percent of the 1,000 plus freshwater fish in the U.S., Canada, and Mexico have gone extinct and another 26 percent are at risk (http://www.sprl.umich.edu/GCL/notes2/introsp.pdf). The principal stressors on these freshwater fish species are habitat destruction (73 percent) introduced species (68 percent), pollution (38 percent), hybridization (38 percent) and over harvesting (15 percent). Although hybridization is categorized as an independent stressor in these figures, most hybridizations are due to human introductions, suggesting that introduced species are the single most important stressor.

In addition to reducing the number of species, mixing of previously geographically isolated ecosystems homogenizes the world's flora and fauna. Once biologically distinct regions and ecosystems are becoming more and more similar, not unlike the effect the proliferation of fast-food restaurants has had on homogenizing once distinct regional cuisines.

Under some conditions, exotic species increase species richness. Species richness increases immediately after the introduction of an exotic. In most cases this is a temporary increase and species richness will decline if the introduced species either dies out or, conversely becomes invasive and impacts native species. In some cases, exotic species appear to be added to a community without causing any obvious impacts. An example is an exotic seagrass, *Zostera japonica*, in the Pacific Northwest. *Z. japonica* has a limited distribution within the estuary and provides at least some of the same functions as provided by the native seagrass, *Zostera marina*, such as food for Brant geese. While *Z. japonica* may be benign, the decade-long lag period before the smooth cord grass, *Spartina alterniflora,* "exploded" to invasive densities in Willapa Bay, Washington cautions against assuming a nonindigenous species will not result in ecological havoc in the future.

IV-2. Hawaiian Biodiversity:

Because of the threats to its unique biota (http://biology.usgs.gov/s+t/SNT/noframe/pi179.htm), Hawaii deserves special mention. Island flora and fauna evolved in isolation from many stresses, such as intense fires and browsing by large herbivores, making them especially vulnerable to novel stresses (Jacobi and Scott, 1985; (https://128.174.5.51/denix/Public/ES-Programs/Conservation/Invasive/hawaii.html). This contention is supported by Wilcove's et al. (1998; http://www.fguardians.org/threats.html) conclusion that invasives are a greater threat to Hawaiian species than those on the continental United States. Additionally, as hubs of global transportation, islands are exposed to high rates of invasions. For example, an introduction rate of 40 plant species per year over the last 200 years is required to account for the more than 8000 introduced plant species in Hawaii. Intentional introductions have also had major impacts; feral pigs are the primary modifier of Hawaii's highland forests both by feeding on native plants and by creating seed beds for exotic weeds (Westbrooks, 1998; (http://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/Invasive/intro.html).

The combined effects of vulnerability and high invasion rates have devastated the Hawaiian flora and fauna. At least 50 percent of the endemic birds and 90 percent of the native land snails have been lost (http://biology.usgs.gov/s+t/SNT/noframe/c102.htm) and Hawaii accounts for almost 40 percent of all the plant species listed as endangered or threatened (http://biology.usgs.gov/s+t/SNT/noframe/pi179.htm).

IV-3. Preservation of Native Flora and Fauna in Public Lands:

Another aspect of biodiversity is the preservation of the native flora and fauna on public lands. This societal value is reflected in the proliferation of volunteer groups to eradicate invasive weeds from public lands (e.g., TNC Weed Listserve at tncinvasives@ucdavis.edu) and by the high priority the National Park Service places on combating invasives. At least half of the 368 National Park System units have serious problems with exotic species (http://www1.nature.nps.gov/facts/ftexotic.htm) and they have concluded that "if exotics are not actively and aggressively managed, the National Park System is at risk of losing a significant portion of its biological resources" (http://www1.nature.nps.gov/wv/exotics.htm).

IV-4. Wildlife:

Declines in charismatic birds, mammals, amphibians, and fishes are a major concern to the public, and invasive species are a significant contributor to many of these declines. Reductions in habitat quality resulting from invasions of purple loosestrife (*Lythrum salicaria*), Arundo, *Spartina alterniflora*, and other exotic wetland species impacts a wide variety of wildlife species. In terrestrial systems, native grazers avoid areas invaded by unpalatable species. Utilization by deer, elk, and bison declined three to four fold in areas dominated by leafy spurge or spotted knapweed (http://www.mtwow.org/FAQ.htm).

Exotic predators are an additional threat. Since its introduction into Guam in the 1950s, predation by the brown tree snake (*Boiga irregularis*) has driven twelve native forest birds to extinction and several others to the brink of extinction (http://www.mesc.nbs.gov/research_briefs/bts/btreesnk.htm). The Indian mongoose (*Herpestes auropunctatus*) was introduced into the Caribbean and Hawaii in the late19th century to rid sugarcane fields of rats. Instead, the mongoose preys mainly on native ground-nesting birds, amphibians and reptiles. The mongoose is responsible for the extinctions of at least seven to twelve birds, reptiles and amphibians in Puerto Rico and islands of the West Indies (http://www.sciam.com/explorations/1999/021599animals/animals.html)

Less is known about the effects of introduced pathogens, but a poultry disease introduced with domestic turkeys contributed to the demise of the last population of heath hens on Martha Vineyard, Massachusetts in the 1930s. More recent threats are the West Nile virus, which infects birds and various mammals (http://nationalatlas.gov/natlas/natlasstart.asp), and African heartwater virus. The African heartwater virus, which can be introduced with ticks on imported reptiles, represents a serious threat to North American bovine herds (http://www.ruu.nl/tropical.ticks/nwl698i.htm).

The California clapper rail provides an example of how invasive species interact with other types of stressors. The clapper rail population has been decimated by hunting, loss of its marshland habitat, and contamination of its food sources. Additionally, the remaining clapper rails fall are preyed upon by several non-native predators such as the red foxes, Norway rats, and feral cats (http://hard.dst.ca.us/hayshore/library/es11_95.htm). Moreover, rails feeding on the introduced ribbed horse mussels (*Geukensia demissa*) can get their beaks or toes trapped when the mussel closes. Trapped juvenile rails can drown on incoming tides (de Groot 1927), and in the California Redwood marsh, as many as 29 percent of juveniles are lost to the ribbed mussel.

The additional mortality resulting from invasive species makes it all the more problematical for endangered populations to recover even when other anthropogenic stressors are mitigated.

IV-5. Ecosystem Sustainability:

In the absence of catastrophic events such as hurricanes, the public expects ecosystems to be "sustainable" with minimal changes in species composition and valued ecosystem functions (e.g., fishing). While this expectation is somewhat naive, the influx of invasive species is changing ecosystems more drastically and much faster than would naturally occur. Dramatic changes resulting from invasions of exotic species can often occur within a decade and are noticeable even by casual observers.

A factor contributing to ecosystem instability is "invasional meltdown" where the introduction of one nonindigenous species promotes the establishment of other introduced species. An example presented at the National Nonindigenous Species Workshop (U.S. EPA, 2001) is that by increasing water clarity, zebra mussels create hard substrate suitable for the invasive Eurasian watermilfoil (*Myriophyllum spicatum*). In turn, Eurasian watermilfoil provides habitat for zebra mussels to settle on. An invasive tree in Hawaii, *Myrica faya*, fixes nitrogen, creating a habitat suitable for the establishment of other invasive plants, which are better adapted to higher nitrogen levels than the natives species (Mack et al., 2000; (http://esa.sdsc.edu/issues5.htm). *Myrica* also attracts Japanese white-eye *(Zosterops japonicus*), an invasive bird species that competes with native birds and disperses *Myrica* seeds. The net effect of these positive feedbacks among invasive species is to accelerate the degradation of native species and ecosystems.

IV-6. Hybridization:

Hybridization of native and introduced species or stocks was the sole or contributing cause to the extinction of at least 3 of the 24 extinctions listed under the Endangered Species Act (http://www.nap.edu/issues/13.4/schmit.htm). In the western states, the endangered Gila trout and the Apache trout are currently threatened by hybridization with introduced rainbow trout. Cross breeding with introduced mallard ducks threatens both the endangered Hawaiian duck and the native Florida mottled duck. Both rainbow trout and mallard ducks were intentionally stocked to enhance fishing and hunting, respectively, again illustrating the conflicting values inherent in many invasive species issues.

The ability to predict whether hybridization will occur is problematic, as demonstrated by *Spartina alterniflora*, which was introduced into Great Britain in ballast water. This Western Atlantic marsh plant initially crossed with the native *Spartina maritima* to form a sterile hybrid, *Spartina townsendii*. However, the sterile hybrid mutated into the fertile *Spartina anglica* which has become the dominant cord grass in Great Britain (http://www.jncc.gov.uk/marine/dns/d2_1_5_1.htm).

V. IMPACTS ON AGENCY GOALS AND POTENTIAL AGENCY ROLES

This section evaluates how invasive species affect the ability of the Agency to achieve its environmental goals and mandates as well as how various regulations could be applied to the management of invasive species. The comments on the application of regulations arose from discussions at the Regional and National Nonindigenous Species Workshops and do not constitute Agency policy, policy recommendations, or a legal review of existing laws and regulations.

V-1. Executive Order on Invasive Species:

Executive Order 13112 on Invasive Species was signed on February 3, 1999 (http://www.invasivespecies.gov). This Executive Order calls for federal agencies to use relevant programs and authorities to:

1) Prevent the introduction of invasive species
2) Detect and respond rapidly to and control populations of such species in a cost-effective and environmentally sound manner
3) Monitor invasive species populations accurately and reliably
4) Provide for restoration of native species and habitat conditions in ecosystems that have been invaded
5) Conduct research on invasive species and develop technologies to prevent introduction and provide for environmentally sound control of invasive species
6) Promote public education on invasive species and the means to address them.

Additionally, the Order states that federal agencies shall "not authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species ... [unless] the agency has determined and made public its determination that the benefits of such actions clearly outweigh the potential harm caused by invasive species; and that all feasible and prudent measures to minimize risk of harm will be taken in conjunction with the actions."

The Executive Order establishes an Invasive Species Council co-chaired by the Secretaries of Interior, Agriculture, and Commerce. Within EPA, a charter member of the Council, the Assistant Administrator for the Office of Research and Development (ORD) is the "principal representative" while Mike Slimak (ORD/National Center for Environmental Assessment (NCEA)) is the Agency representative on the Council. An informal Agency group, the Nonindigenous Species Workgroup (NISWG), composed of representatives from the Program Offices, Regions, and ORD has been used to help coordinate the Agency's response to the Council (contact: Henry Lee II, lee.henry@epa.gov).

The Council has prepared a National Invasive Species Management Plan that is to be the "blueprint for coordinated Federal action". The final version of the Plan was released on January 18, 2001 and is available at http://www.invasivespecies.gov. The Plan lays out action items for federal agencies, including specific actions targeting the EPA as a lead agency as well as other actions where the EPA could have a role. These recommended actions could significantly affect the Agency, in particular the Office of Water, Office of Prevention, Pesticides, and Toxic Substances, Office of International Affairs, and Office of Research and Development. Appendix 1 lists the specific action items potentially affecting the EPA; our analysis suggests that 21 of the 57 action items relate to the EPA to some degree. Appendix 1 also presents a preliminary interpretation as to the effects of the action items on the EPA.

V-2. Agency Credibility and GPRA Goals:

The EPA has historically focused on pollutants, even though EPA's mission statement is much broader, and includes a goal that "Environmental protection contributes to making our communities and ecosystems diverse, sustainable and economically productive" (http://www.epa.gov/history/org/origins/mission.htm). As described in this document, invasive species are one of the major anthropogenic stressors degrading the diversity, sustainability, and economic productivity of our Nation's ecosystems. The public views the EPA as the protector of the environment, and one conclusion to come out of all the Regional Nonindigenous Species Workshops was that the EPA should take a greater role in managing invasive species. Another concern raised at the Regional Workshops was that the failure to address an obvious high priority risk undermines EPA's commitment to the risk assessment approach. Failure to address invasive species while focusing on less important stressors may taint the Agency with "the operation was a success but the patient died" reputation.

Besides credibility with the public, the Agency's political credibility will suffer if it fails to achieve its Government Performance Results Act (GPRA) Goals and Objectives as a result of invasive species. Because they affect such a wide range of ecological processes, invasive species potentially affect nearly every GPRA Objective that includes an ecosystem endpoint or a terrestrial-aquatic flux. Appendix 2 presents our analysis of the impacts on GPRA Goals and Objectives. Appendix 2 should be used as a starting point, and Program Offices and Regions should conduct their own analysis. Nonetheless, it is apparent that invasive species are likely to affect the implementation and success of a number of GPRA Objectives across a suite of programs and media.

V-3. NEPA:

The National Environmental Policy Act (NEPA) requires environmental assessments (EAs) and environmental impacts statements (EISs) for all federal actions that might impact the environment. Under NEPA, EPA has broad review responsibilities that have been delegated to the Regions and the Office of Federal Activities. Nonindigenous species potentially affect the Agency's reviews in at least four ways. 1) The reviews should evaluate whether the proposed actions will promote the introduction and/or spread of nonindigenous species. Addressing these types of effects will require evaluation of ecological processes not normally included in most EAs and EISs, such as whether the proposed actions will create habitats prone to invasions. 2) The reviews should evaluate whether invasive species have reduced the "assimilative capacity" of the native species to such an extent that more protective limits are required on other anthropogenic stressors. 3) The Invasive Species Council in cooperation with the President's Council on Environmental Quality (CEQ) is developing guidance on the use of NEPA in managing invasive species by August 2001. Presumably, the Agency's role in reviewing EAs and EISs addressing invasive species would increase if NEPA is promoted as an omnibus regulatory tool for invasive species. 4) The fourth role is the review of biocontrol agents, which is discussed below.

V-4. Biocontrol:

Biocontrol is the release of host-specific predators or pathogens to control invasive species populations. There have been some historical disasters resulting from such releases (e.g., rabbits in Australia, mongoose in Caribbean), and there remains a real risk even when potential biocontrol agents undergo more rigorous host-specificity tests. An Eurasian weevil released to control musk thistle is now attacking native thistles, including an endangered species (http://esa.sdsc.edu/issues5.htm). Even with these concerns, biocontrol is one of the few management tools available once a nonindigenous species become invasive, and the Invasive Species Management Plan (see "V-1. Executive Order on Invasive Species") promotes its use. Therefore, the use of biocontrols is likely to increase in both agricultural and non-agricultural settings.

Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), EPA regulates the release of microorganisms and viruses used for biocontrol. The Agency has a review role with larger organisms (e.g., insects) used for biocontrol. According to the USDA (http://www.aphis.usda.gov/nbci/nbci.html), there "are two bases for the regulation of biological control organisms -- either along with plant pests under [USDA's] APHIS' FPPA-based authority, or along with pesticides under EPA's FIFRA-based authority -- neither of which suits the actual nature and scope of biological control." (FPPA is the Federal Plant Pest Act that regulates the release of organisms "which can directly or indirectly injure or cause disease or damage in any plants".) The USDA has a Technical Advisory Group (TAG) to review biocontrol permits (http://www.aphis.usda.gov/ppq/ss/tag/), on which there is one EPA representative. Based on our preliminary evaluation of the process, it is unclear whether the EPA has the authority to take a more active role in the evaluation of biocontrols under its NEPA authority and, if so, what role it should take.

V-5. Ballast Water and NPDES Permits:

By taking on and then discharging ballast water, ships transport massive quantities of water, estimated at more than 21 billion gallons/year discharged into United States waters (http://courses.washington.edu/sma550o/BWpetitn.html). This is equivalent to a 58 MGD discharge. These discharges inoculate coastal and inland waters with a plethora of exotic organisms, and ballast water discharges are estimated to have resulted in the introduction of more than 40 species into the Great Lakes and 50 into San Francisco Bay in the last 30-40 years (NRC, 1996; http://www.nap.edu/books/0309055377/html/index.html).

Spurred on by the ecological and economic impacts of zebra mussels in the Great Lakes, the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) was passed in 1990, requiring ballast water exchange or equivalent treatment for all ships entering the Great Lakes from outside the Exclusive Economic Zone (EEZ). In recognition of the risks to other water bodies, the National Invasive Species Act (NISA) was passed in 1996 (modified in 1999). NISA requires mandatory mid-ocean ballast water exchange or equivalent treatment for ships entering the Great Lakes and parts of the Hudson River from outside the EEZ. It also establishes a voluntary ballast water exchange program with mandatory reporting for all ships entering U.S.

waters from outside the EEZ (http://invasions.si.edu/ballast.htm and http://www.nemw.org/biopollute.htm).

Within 24-30 months of its implementation in July 1999, the Coast Guard is to report to Congress on the effectiveness of the voluntary approach and whether a mandatory ballast water exchange is needed. The first year's results indicate poor compliance with only 21 percent of the ships filing the mandatory report (http://invasions.si.edu/NABS1stAnnualReport.pdf). Of the ships that voluntarily exchanged ballast water, 79 percent of them conducted only a partial exchange of their ballast, leaving the potential for the introduction of exotic species. The current voluntary exchange program is administered by the Coast Guard with the Smithsonian Environmental Research Center (SERC) serving as the clearinghouse; the EPA is only incidentally involved.

In contrast to NISA, the EPA is directly involved with ballast water management under the Uniform National Discharge Standards for Armed Forces Vessels Act (UNDSAF), which amended the Clean Water Act (CWA) in 1996. Under UNDSAF, the EPA is working with the Armed Forces to establish a single set of national pollution guidelines for all Navy ships which will likely include mid-ocean ballast water exchange.

A potentially greater role for EPA is the regulation of ballast water discharges under the NPDES permitting process. In January 1999, a group of fifteen environmental, fishing, and water supply groups petitioned the EPA to repeal a regulatory exclusion exempting the discharge of ballast water from point-source permitting requirements (http://courses.washington.edu/sma550o/BWpetitn.html). The petitioners argued that the EPA does not have the authority to exclude "discharge[s] incidental to the normal operation of a vessel" (e.g., ballast water, bilge water). As noted by the petitioners, repealing this exclusion would result in "paving the way for the regulation of ballast water discharges under the CWA." The EPA did not release a final response to the petition so that "In January 2001, the groups informed EPA that legal recourse would be necessary if the petition was not answered. EPA responded on February 7 by telling the groups about its involvement in various committees that are attempting to address the exotic species problem. The agency declined to give the organizations a date by which it would respond to their petition." (see "News/Media" at http://www.northwestenvironmentaladvocates.org). Then in April 2001, a lawsuit was filed against the EPA in the federal district court in San Francisco alleging that "the EPA has violated the Administrative Practices Act by failing to respond to the petition."

Regardless of EPA's response to the petition and lawsuit, the decision is likely to be challenged either by the shipping industry and ports or by environmental groups and their allies. While there is opposition from the shipping industry to regulating ballast water under NPDES, representatives from the shipping industry stated at the Region 4 Nonindigenous Species Workshop (U.S. 1999a) that they would prefer a "practical" national or international regulation than a patchwork of state regulations like those recently promulgated in California and Washington, and being considered in Oregon (for summary of state laws see http://ballast-outreach-ucsgep.ucdavis.edu).

Even as the debate over ballast water exchange continues, there is a growing consensus that mid-ocean ballast water exchange is not sufficiently protective because of incomplete exchange of ballast water and organisms living in the sediments or on the walls of ballast tanks. Most experts now believe some type of ballast water treatment will be required to sufficiently lessen the risk of new introductions. Treatment could either be on-board or dockside. Techniques under consideration include filtration, centrifugation, biocides, heat, UV radiation, and discharge of ballast water into sewage systems. The two primary biocides being evaluated are oxidizing biocides, in particular chlorine and ozone, and nonoxidizing biocides, in particular glutaraldehyde. Presumably, the EPA would permit any effluent discharged from these treatments, especially if biocides were used. Another potential role for EPA is in the validation of these treatment systems through the Environmental Technology Verification (ETV) program or at the ORD laboratories.

V-6. Total Maximum Daily Loads:

Under Section 303(d) of the Clean Water Act (CWA), States, Territories and authorized Tribes must identify impaired and threatened waters every two years. Impaired waters are those that do not meet applicable water quality standards even after controlling point sources of pollution. Threatened waters are those that currently meet water quality standards, but for which adverse declining trends indicate that standards will be exceeded by the next 303(d) listing cycle. States, Territories and authorized Tribes are required to establish priority rankings for impaired waters and develop TMDLs for these waters. A TMDL specifies the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and allocates pollutant loadings among point and nonpoint pollutant sources. EPA must approve or disapprove lists and TMDLs established by States, Territories and authorized Tribes. Invasive species potentially relate to TMDLs in three ways: 1) TMDL listings for invasive species, 2) use of TMDLs to indirectly manage exotic species, and 3) affects of exotic species, especially weeds, on pollutant loadings.

Approximately 900 waters in 19 States are listed for invasive species on the 1998 303(d) list. The majority of these noxious aquatic plants are affecting lakes, many of which are also impaired by nutrients. Current regulations require that TMDLs be established only for pollutants. Since the CWA includes “biological materials” in its definition of “pollutant”, and since one of the primary objectives of the Clean Water Act is the restoration and maintenance of biological integrity of the Nation’s waters, an invasive species may be a “pollutant” for CWA purposes in some circumstances. In 1978, EPA decided that all pollutants, under proper technical conditions are suitable for the calculation of TMDLs. EPA believes that determination of whether a particular invasive species is a pollutant requires a case-by-case analysis. In the future, EPA may reevaluate whether materials such as “noxious aquatic plants” are pollutants, generally or in individual situations, for Clean Water Act purposes.

One recent case has been for noxious aquatic plants affecting two Louisiana lakes. Under the terms of a recent partial consent decree in Louisiana, and based on the strong correlation between reduction of nutrients and reduction of noxious aquatic plant growth, EPA established a nutrient and noxious aquatic plant TMDL for two lakes in Louisiana (December 22, 2000). In this particular case, EPA considered the noxious aquatic plant growth in Chicot Lake and Lake Cocodrie to be a “pollutant” within the meaning of Section 502(6) of the Clean Water Act.

A second case under consideration is a draft Exotic Species TMDL for San Francisco Bay, California, completed by the San Francisco Regional Water Quality Control Board, State of California, for EPA Region IX (May 8, 2000 http://www.swrcb.ca.gov/rwqcb2/Tmdl.pdf). San Francisco Bay waters are listed on the 1998 303(d) list as impaired by exotics, and are ranked as high priority for TMDL development. The major source of exotic species introductions to the Bay is via ships' ballast water. While EPA has not taken the position that exotic species in ballast water qualify as pollutants, or made any determination about the suitability of TMDLs for exotic species in ballast water, EPA has stated its strong support for the State's emphasis on protecting the Bay ecosystem from the effects of exotic species. In this draft TMDL, ballast water discharges are identified as the primary source of new introductions, and the loading for new exotic species is set at zero. No action is proposed regarding the existing exotic species under the draft TMDL. Implementation of the San Francisco Bay draft TMDL is phased, and the first stage is to use the best practical technology (BPT), which was determined to be mid-ocean ballast water exchange. However, since ballast water exchange alone would not achieve the loading requirement, the draft TMDL anticipates that some type of ballast water treatment would be required in latter phases of the draft TMDL implementation. This draft TMDL has not been approved by the State, and therefore has not been submitted to EPA for approval.

Prior to the completion of the draft San Francisco Bay TMDL, California passed state law AB 703 (October 10, 1999) which requires mandatory mid-ocean ballast water exchange, essentially equivalent to the requirement for the Great Lakes under NISA (see "V-5. Ballast Water and NPDES Permits"). While California state law AB 703 implemented the BPT phase of the draft TMDL, it also prohibits the Regional Boards from issuing either less or more stringent requirements (e.g., ballast water treatment) until the law "sunsets" in January 2004. Because the technologies for ballast water treatment are only now being developed and verified, the delay in requiring ballast water treatment is not considered a major limitation to the phased implementation of the draft TMDL.

Theoretically, TMDLs could also be used to indirectly manage existing invasive species (vs. new introductions as in San Francisco Bay draft TMDL) by controlling the loadings of pollutants that promote exotic species. For example, tubifex worms, the intermediate hosts of whirling disease (see "II-5. Recreation - Fishing"), are abundant in organically enriched sediments. Reducing loadings of fine sediments and organic matter could limit their population, which in turn could reduce the incidence of whirling disease.

Finally, invasive species can indirectly affect TMDL development by altering loadings of conventional and toxic pollutants. The particular effects will depend upon the nature of the pollutant, ecosystem, and invasive species. By increasing erosion, terrestrial weeds in the arid west may double the loadings of clean sediments and pollutants into surface waters (see "II-10. Hydrologic and Sediment-Transport Related Services"). Depending on the species, terrestrial weeds can either increase or decrease soil nitrogen (see "10-D. Nutrient Fluxes"), which presumably would affect loadings from runoff. In some water bodies, aquatic weeds store and then release substantial amounts of nutrients, which will affect both seasonal changes in nutrient loadings and their ecological impacts (see "10-D. Nutrient Fluxes"). Failure to account for these biologically mediated transport processes can introduce considerable error in the predictions of background or "natural" loadings, and hence the allowable loadings from point and non-point sources.

V-7. Wetland Restoration:

Estimates put the loss of existing wetlands at 70,000 - 90,000 acres per year (http://www.epa.gov/OWOW/wetlands/vital/status.html). To counter this trend, the Agency has a goal of "a net increase of 100,000 acres of wetlands" per year by 2005 (GPRA Goal 2, Objective 2, Subobjective 2.2; see Appendix 2). In achieving this goal, one thrust should be to stop or slow the loss of existing wetlands. The problem is that invasive wetland plants, such as purple loosestrife, are invading and fundamentally altering thousands of acres of wetlands. These invasions result in the loss of key wetland functions, such as bird habitat, if not the actual loss of wetlands per se.

The impact of these invasions on achieving the Agency's GPRA Goal depends upon whether the acreage of wetlands is determined by the acreage of functional, native wetlands or by the presence of any wetland plant species regardless of how undesirable. Although the definition of wetlands is a contentious policy and legal decision, we believe including highly altered wetlands as part of the 100,000 acres is a temporary fix that obscures the more basic problem of the net loss of wetland functions. Long-term ecological, political, and economic interests would best be served if the GPRA Goal is achieved by an annual increase of native wetlands.

The second element in achieving this GPRA Goal is to restore or create new wetlands. The importance of using native species in restoration is now recognized as one of EPA's principles in restoring aquatic resources (http://www.epa.gov/owow/wetlands/restore/principles.html#3), and is required by the Executive Order unless there are compelling reasons to use non-native species (see "V-1. Executive Order on Invasive Species"). A thornier problem is that newly constructed or restored wetlands are "disturbed" habitats and as such are vulnerable to invasions. Establishment of exotic weeds in these constructed wetlands could serve as a seed source for invasions of neighboring wetlands. This concern was raised at the wetland/riparian session of the Region 9 Nonindigenous Species Workshop, where several wetland experts recommended that no new wetlands be constructed in San Francisco Bay until it can be demonstrated that the new sites will not be overtaken by invasives, in particular *Spartina alterniflora*.

The possibility of "restored" wetlands infecting neighboring native habitats raises questions about the ecological validity of wetland mitigation banks. It is critical, therefore, to develop and validate restoration techniques for native species for various wetland types. Potential approaches include both restoration techniques (e.g., timing of restoration, planting rapidly growing "restoration" species to minimize initial invasions, better replication of microhabitats) and control techniques (e.g., removal of nearby invasives, use of selective herbicides).

V-8. Ambient Water Quality and Pollutant Dynamics:

Invasive species can degrade water quality both by increasing loadings and by altering pollutant dynamics within water bodies. Some of the primary mechanisms (see "II-10. Hydrologic and Sediment-Transport Related Services") include: 1) decreased stream flow; 2) increased erosion and runoff; 3) increased sediment deposition from wetland plants and freshwater and estuarine bivalves; 4) terrestrial weeds increasing nutrient loading by increasing soil nitrogen; and 5) sudden release of nutrients with the senescence of aquatic weeds. The impacts on water quality can be substantial. A modeling simulation of Saginaw Bay (Endicott et al., 1998) predicted that zebra mussels increase the flux of particles and particle-associated contaminants from the water column to the sediment by seven-fold.

Aquatic invasive species can also affect the potential for biomagnification and the transfer of pollutants to wildlife by altering food webs. The potential for biomagnification of PCBs increases with invasions of zebra mussels (Bruner, et al. 1994). Changes in the food web following the invasion of the Asian clam (*Potamocorbula amurensis*) into San Francisco Bay has resulted in higher selenium concentrations in diving ducks (Thompson and Luoma, 1999) and perhaps sturgeon (http://iep.water.ca.gov/eet/min9706.html).

Invasions of exotic pests also indirectly degrade water quality by resulting in increased pesticide usage. As discussed below ("V-16. Pesticide Use and Pollution Prevention"), a substantial portion of all pesticides are targeted for exotic pests; presumably these same pesticides are also responsible for a corresponding proportion of pesticide-related water quality problems.

In some cases, nonindigenous species improve water quality. As mentioned, *Hydrilla* may reduce algal blooms by binding the nutrients during the active growing season (see "10-D. Nutrient Fluxes"). *Hydrilla* and water hyacinth have also been used to remove soluble pollutants from contaminated ponds. Perhaps the largest scale improvement in water quality is due to the zebra mussel. Filtration of water-column particulates by zebra mussels has been sufficient in parts of the Great Lakes to result in the clearest water in decades. While decreasing turbidity reduces the most visible manifestation of eutrophication, increased water clarity without a concurrent decrease in nutrient concentrations can result in unanticipated effects including increases in harmful blue-green algae or nuisance macrophytes (see "V-9. Drinking Water Quality").

V-9. Drinking Water Quality:

Blooms of the blue-green algae *Microcystis* and benthic macroalgae have recently resulted in taste and odor problems in portions of the Great Lakes. One explanation is that by increasing water clarity and reducing the natural phytoplankton populations, filtration by zebra mussels has created conditions promoting these nuisance algae (Vanderploeg and Nalepa, 1995 in Glassner-Shwayder, 2000; http://www.sgnis.org/publicat/96vander.htm). Taste and odor problems can also result from decaying mats of the exotic Eurasian watermilfoil and other aquatic weeds. Water-borne pathogens from ballast water discharges are another potential threat, though we are not aware of any cases of disease resulting from ballast water discharges into drinking water supplies (versus ingestion of contaminated shellfish).

V-10. Open Ocean Disposal of Dredge Material:

Under the Marine Protection, Research, and Sanctuaries Act (MPRSA), the ocean disposal of materials that would "adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities" is prohibited or severely limited. Environmental concerns to date have focused on the toxicity and bioaccumulation potential of dredge materials, though there is a growing recognition that dredge material is also a potential transport vector for nonindigenous species.

Ocean disposal of dredge material inoculates offshore ecosystems with literally millions of nonindigenous individuals, though it is not clear how well these species survive in an oceanic environment. Even if the nonindigenous species do not become established offshore, ocean disposal may facilitate their transport along the coastline to other near-coastal habitats. Another risk is the direct transport of nonindigenous species on the dredger, though this can be minimized by careful cleaning between operations. These various risks should be evaluated both in locating dredge disposal sites and in assessing any particular disposal operation. If the risks are too great, other disposal options might be required.

V-11. Inland Disposal of Dredge Material:

Section 404 of the Clean Water Act regulates the discharge of dredged or fill material into all fresh, estuarine, and marine waters landward of the territorial sea. Discharge is prohibited if the material "will have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas), wildlife, or recreational areas." Sediment toxicity, bioaccumulation potential, and wetland loss have been the primary environmental concerns to date; as with open ocean disposal, there is a growing recognition for the potential transport of invasive species. However, with inland disposal there is a greater risk of the transported organisms becoming established since inland dredge and disposal habitats are more likely to be similar than are near-shore and oceanic habitats. An additional risk with inland disposal is the transport of exotic plants or their seeds. As with ocean disposal, the potential for transporting nonindigenous species needs to be considered both in locating disposal sites and in evaluating the environmental risks from any particular disposal operation.

V-12. Endangered Species Act:

The Endangered Species Act (ESA) is administered by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service. EPA's role is to coordinate the Clean Water Act with those two agencies so as not to jeopardize endangered species. As discussed above ("IV-1. Biodiversity"), invasive species are second only to habitat degradation as a stressor on threatened and endangered species. Because the stress imposed by invasive species reduces the "assimilative capacity" of these restricted populations to cope with other insults, more stringent point and nonpoint controls may be required to maintain viable populations. As impacts from invasive species increase, pollutant control measures that have been sufficient historically may no longer prove protective, and stricter pollution controls may be required in the future just to maintain the status quo.

V-13. Biocriteria:

Biological criteria are "numeric values or narrative expressions that describe the reference biological condition of aquatic communities inhabiting waters of a given designated aquatic life use" (http://www.epa.gov/owow/monitoring/tech/chap01.html). Invasions of nonindigenous species confound the interpretation of many of the approaches to establishing biological criteria. Historical reference conditions are frequently used as a standard for defining ecological condition or as a calibration for ecological metrics. However, in a highly invaded community it is difficult to ascertain whether differences between historical and present conditions are due to exotic species, other anthropogenic stressors, or some interaction between the two. For example, is the change in trophic structure in San Francisco Bay solely a consequence of the invasion of the Asian clam (*Potamocorbula amurensis*) or does sediment contamination contribute directly or indirectly to the changes (see Lee et al., 1999; U.S. EPA, 2001)?

Even if an historical approach is not used, the presence of nonindigenous species confounds the interpretation of commonly used indices of community structure (e.g., diversity, proportion of pollutant-tolerant groups) and function (e.g., proportion of different feeding groups). For example, amphipods are frequently used as a "pollution-sensitive" taxon, yet the total density of amphipods increased along a DDT gradient because of the high density of a pollutant-tolerant nonindigenous amphipod (Lee et al., 1994). As discussed above ("IV-1. Biodiversity"), introductions of nonindigenous species can increase species richness. A possible scenario is that a disturbed site could have a higher species richness than a reference site because of a high invasion rate. Under this scenario it is not clear how to interpret species richness as a measure of ecological condition.

There is a need to develop ecological indicators that capture the impacts of nonindigenous species on ecosystem structure and function. A few structural indices have been proposed based on the percentage of native versus nonindigenous species (e.g., "native species indicator" of the NRC, 2000a; (http://www.nap.edu/books/0309068452/html). One limitation of the existing indicators is that they do not account for future impacts of nonindigenous species that are presently at low numbers but that have the potential to "explode" to invasive densities. A lake recently invaded by zebra mussels would not have been measurably altered by this invasive species, yet any biocriterion failing to recognize the lake's low ecological sustainability would give a misleading picture of its "ecosystem integrity". Another policy/science issue is how to incorporate "desirable" non-native species into biological criteria. One example is the stocking of exotic trout versus their impacts on native fish assemblages. A biocriterion based on recreational fishing would rank a stocked stream in good condition while a biocriterion based on a comparison to a natural reference would indicate the ecosystem is impaired.

V-14. Monitoring/Research Programs and Taxonomic QA/QC:

Tens, if not hundreds, of millions of dollars are spent each year for compliance monitoring of aquatic communities throughout the country (e.g., 305b, 301h, NPDES, etc.). These regulatory programs could substantially contribute to the detection of range expansions of existing invasive species and act as early warning systems for newly introduced nonindigenous species.

Developing such systems requires taxonomy of high quality (e.g., not mislabeling a new exotic as a local species). Achieving this level of taxonomic accuracy will require EPA to institute taxonomic QA/QC requirements equivalent to those used for chemical analysis. With its experience with analytical QA/QC, the EPA has the infrastructure to institute these requirements, though it would be necessary to partner with other entities (e.g., Smithsonian Institution) with more taxonomic expertise to establish the standards. Requiring high quality taxonomy will require additional resources, but these costs could be justified by the need to separate the effects of invasive species versus pollutant effects. One limitation is the lack of regional lists of nonindigenous species for many areas, as was developed for San Francisco Bay (Cohen and Carlton, 1995), though these could be developed at a relatively modest cost. Another limitation is the general lack of trained taxonomists for many taxa.

ORD research programs can also contribute to the detection of nonindigenous species. In particular, EMAP, which uses a probabilistic sampling approach to estimate the ecological condition of the Nation's waters (http://www.epa.gov/emap), could serve this purpose. Probability-based sampling provides an unbiased estimate of the extent of the targeted stressors, and this sampling approach determined that introduced fish were one of the most regionally extensive stressors in the Mid-Atlantic Highlands area (see "II-5. Recreation - Fishing" and http://www.epa.gov/emap/maia/html/rabrief/slide14.html). More recently, results from the EMAP Western Pilot were analyzed to evaluate differences in the extent of invasion among Oregon, Washington, and California small estuaries and whether the extent of invasion was related to estuary size (Lee et al., 2001).

V-15. Ecological Risk Assessment:

Ecological risk assessments are a promising approach to addressing some of the complex problems associated with invasive species. For example, they could be used to: 1) evaluate proposed intentional introductions; 2) compare the relative environmental impacts of control scenarios for unintentional introductions (e.g., no treatment vs. aggressive use of herbicides); 3) evaluate the risks from ballast water discharges from different parts of the world; or 4) evaluate the impacts of invasive species in comparison to other anthropogenic stressors. One of advantage of a risk assessment approach is the formalization of the problem and of the approach to assessing the risks.

There are, however, a number of complexities inherent in assessments with invasive species. To an even greater extent than with pollutants, it is critical to define measurable assessment endpoints of value to the public. While nearly everyone agrees that pollutants are undesirable, there is much less agreement about what constitutes a "good" versus "bad" species or ecosystem. This lack of agreement renders the use of broad endpoints such as "ecosystem integrity" of limited use for invasive species. For example, would ecosystem integrity be considered impaired if the species composition had been substantially altered but the ecosystem still provided ecological functions similar to native habitats? Other complexities include how to incorporate the beneficial aspects of nonindigenous species in the assessment and to what extent the "precautionary principle" should be applied to account for potential future impacts. Even a simple attempt at comparing the relative impacts of nonindigenous species versus those from sediment contamination in San Francisco Bay revealed the difficulty in defining the "problem" and how to compare impacts from fundamentally different types of stressors (U.S. EPA, 2001; Lee et al., 1999).

Even when assessment endpoints have been identified, predicting the ecological risks associated with invasive species is more difficult than with pollutants. Many of these complexities arise from the difficulties in predicting population dynamics of any species, much less the species-to-species interactions inherent in invasions (e.g., invasional meltdown). Additionally, there is the highly stochastic nature of invasions and predicting the effects of natural and anthropogenic disturbances on invasions. While these problems are difficult, they can be approached over time in incremental steps with a sufficient research effort. An alternative is to utilize large safety factors to account for the various uncertainties, but this may prove politically unacceptable in many cases.

Although these complexities have not yet been rigorously incorporated into risk assessment procedures, several general guidelines for invasive species are available. The Aquatic Nuisance Species Task Force developed guidelines for aquatic species (ANSTF, 1996; (http://ANSTaskForce.gov/gennasrev.htm), which were applied to an assessment of the risks of viruses spreading from foreign shrimp aquaculture to U.S. aquaculture and wild shrimp populations (http://www.epa.gov/nceawww1/svra.htm). USDA's APHIS has "guidelines for conducting pest-initiated, qualitative pest risk assessments specifically for determining whether or not a weed species should be listed in the FNWA [Federal Noxious Weed Act] regulations." (http://www.aphis.usda.gov/ppq/weeds/weedsrisk99.html). The USGS, National Park Service, and University of Minnesota created decision support software to rank the relative risk from existing exotic weeds (http://www.npwrc.usgs.gov/resource/2000/aprs/aprs.htm). While these guidelines are important first steps, both the risk assessment process and the underlying science needs to be further developed before accurate quantitative estimates of risk are possible.

V-16. Pesticide Use and Pollution Prevention

A substantial proportion of all pesticides are targeted for use on exotic species. One hundred twenty-three of the 140 plants on California's Noxious Weed List are nonindigenous. Assuming that herbicide usage is proportional to the number of weed species, almost 90 percent of the herbicides used in California are targeted for exotic weeds. Nationally, about 65 percent of all weeds are exotic, which should generally reflect herbicide usage. A similar pattern is seen with insects, where approximately 40 percent of insect and mite pests in agricultural systems are exotic (Pimentel, 1993). These usage patterns suggest that a major portion of all the ecological and human health impacts resulting from pesticides is a consequence of attempting to control invasive species.

The relative proportion of pesticides targeted for exotic pests is likely to increase. Only about a third of the 6741 plant species considered weeds somewhere in the world are presently found in the contiguous United States (Holm et al., 1979 in Westbrooks, 1998), a staggering pool of potential exotic weeds. As pointed out in the recent "The Future Role of Pesticides in U.S. Agriculture" (NRC, 2000b; (http://www4.nationalacademies.org/news.nsf/isbn/0309065267?OpenDocument), "recent reductions in trade barriers increase the chances that nonnative pests will find their way onto American soil. New, environmentally compatible chemical pesticides will be needed to complement a variety of prevention strategies to combat such pests." This continual development of new pesticides increases the probability of unanticipated ecological and human health impacts.

Applying the same logic to invasives species as is applied to toxic pollutants, the most cost-effective and environmentally-friendly approach to mitigating these impacts is pollution prevention - either preventing the introduction of new exotic pests or, if that fails, a rapid response to control new introductions while they are still localized. The EPA has a relatively minor role in the prevention of new terrestrial pests, which largely falls under the jurisdiction of the USDA. EPA's role in the prevention of new exotics into aquatic ecosystems could be substantial if the Agency regulates ballast water discharges under NPDES (see "V-5. Ballast Water and NPDES Permits"). One key role for the EPA in rapid response is the emergency registration of pesticides (see "V-17. Pesticide Registration").

V-17. Pesticide Registration:

Under Section 18 of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the EPA can authorize emergency exemptions to a pesticide's registration, such as for 1) use on crops not listed in the registration, 2) at higher concentrations, or 3) for the use of a new pesticide before the registration process is completed. Dr. Robert Eplee (U.S. EPA, 2001) emphasized the importance of being able to control invasive weeds by using herbicides outside of their existing registration. He presented the example of witchweed, which devastates corn crops. The most effective herbicides for this weed appear to be paraquat (expanded use), oxyfluorfen (new pesticide), or ethylene (expanded use).

Another of Dr. Eplee's points was that "weeds won't wait". Because of the urgency to control newly introduced exotic pests while their populations are still localized, Section 18 could become an important mechanism in approving the use of effective pesticides in a timely fashion. Recognizing the importance of pesticides in controlling exotic pests, one of the actions specified for the EPA in the National Invasive Species Management Plan (see "V-1. Executive Order on Invasive Species") is to develop a proposal to "utilize current programs to facilitate development, testing, and training of personnel concerning proper use of environmentally sound pesticides in controlling invasive species populations ..." by January 2002 (see Appendix 1).

There is little economic incentive for pesticide manufacturers to register low-use pesticides for newly introduced exotics, especially if they are not likely to become agricultural pests. In these cases, a federal agency (other than EPA) or state agency could act as the registrant. A precedent is the lampricide used in the Great Lakes where the U.S. Geological Survey-Biological Resources Division (USGS-BRD) is the registrant under a memo of understanding with the Great Lakes Fishery Commission (GLFC). It is not clear how, or if, having a federal or state agency as the registrant would change the registration procedure.

V-18. Superfund and Phytoremediation

As Superfund moves from the problem identification/litigation phase into remediation and maintenance, the ecological and political ramifications of invasive species become more important. The primary issues relating to Superfund are similar to those with wetland remediation (see "V-7. Wetlands Restoration") - use of native species in remediation, whether remediated sites are prone to invasion, and whether remediated sites serve as centers for the invasion of surrounding habitats.

Historically, Superfund has approached remediation primarily from an engineering perspective of stabilizing or cleaning up soils rather than restoring native habitats. Accordingly, Superfund has often relied on non-native grass species for erosion control and non-native plants for phytoremediation. For example, the Phytoremediation Bibliography, (http://www.clu-in.org/products/phytobib/bibm-p.html#O), indicates that the invasive water hyacinth has been used in clean-ups. It is our impression that Superfund has become more aware of the risks of using invasive species. In any case, use of invasive species is prohibited under the Executive Order (see "V-1. Executive Order on Invasive Species") unless "the agency has determined and made public its determination that the benefits of such actions clearly outweigh the potential harm caused by invasive species; and that all feasible and prudent measures to minimize risk of harm will be taken in conjunction with the actions."

The Executive Order has raised a number of policy/legal questions regarding the Superfund process, including: 1) can the Executive Order be used as a requirement to restore Superfund sites to native habitats; 2) should Superfund project managers include control of invasives in the records of decision; 3) can EPA require responsible parties to assume the financial and technical burden of administrating invasive species control during remediation, monitoring, and maintenance; and 4) is it possible to generally include non-native species in decisions or do the non-native species need to be identified in the decision? These questions are beyond the scope of this document, but are indicative of the types of issues that invasive species are raising in several regulatory programs.

V-19. Air Quality:

As discussed above ("II-12. Fires"), invasions of exotic weeds can substantially increase the frequency and intensity of wild fires. In addition, controlled burns are used to manage certain exotic weeds. Presumably, these fires could increase particulate concentrations, at least locally. However, we are unaware of any cases linking fires associated with invasive species to air quality violations. Air quality may also affect invasive species. In particular, atmospheric deposition of nitrogen may promote invasive weeds in certain ecosystems.

VI. RESEARCH NEEDS

No ORD report would be complete without a list of research needs — ours is given in Appendix 3. The research topics in Appendix 3 all potentially relate to EPA's overall mission. Additional discussion of research topics can be found in the summaries of the National and Regional Nonindigenous Species Workshops (U.S. EPA, 2001, Lee et al., 1999, and Glassner-Shwayder, 2000). The primary purpose of listing these research topics is as a catalyst for discussions with the Program Offices and Regions in identifying the highest priority needs. We need to emphasize that we do not propose that EPA should, much less has the resources, to address all these research areas. Additionally, as extensive as the list is, it is possible that some high priority topics may have been omitted.

Several of these research needs, especially those related to assessing ecological condition, can be integrated into ongoing projects with little change in their goals or methods and with minimal additional resources. Other projects would require a focused effort, such as an assessment of ballast water treatment alternatives. Because of the scope of the invasive species issue, the best strategy is a combination of in-house research, extramural research, and partnering with the Program Offices, Regions, and other federal and state agencies. While such integration is an often-stated goal, one of the functions of the Invasive Species Council is to help coordinate among various agencies. Additionally, the Invasive Species Council will submit a crosscutting budget proposal for FY03 to "adequately fund Federal invasive species research programs." which could supplement any Agency in-house or extramural resources.

While a number of other agencies are involved in invasive species research, EPA brings a unique mix of talents and skills to the problem. More than most other agencies, EPA has a history of at least attempting to approach environmental problems with an ecosystem approach versus a single species approach. This more "holistic" view will be critical for addressing some of the key questions. Additionally, with its broad environmental mandate EPA has experience with terrestrial, wetland, and aquatic ecosystems. EPA's experience with risk assessment will also be key in addressing various questions. Finally, though frustrating at times, the interaction between ORD and the regulatory programs should help keep the research from becoming "too academic".

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VII. CONCLUSIONS

Invasive species are literally changing the American landscape, and the examples provided in this document only touch on the range of ecological impacts. Every major terrestrial, wetland, and aquatic ecosystem has been invaded and nearly every ecosystem service has been degraded to some degree. Invasive species are responsible for more ecological havoc than all pollutants combined, second only to habitat loss. Ecological conditions will continue to degrade unless the existing invasive species are actively managed and the influx of new exotics is drastically reduced.

It is becoming increasingly recognized that invasive species also represent a human health threat. It is not beyond the realm of possibility that one of the increasingly common exotic diseases could result in a regional or national outbreak. One vector of particular importance to the EPA is the transmission of water-borne diseases, in particular cholera, through ballast water discharges. Because of their prevalence as agricultural and household pests, invasive species are indirectly responsible for a substantial proportion, if not majority, of all human pesticide exposures.

Compared to other federal agencies EPA has not been active in addressing invasive species. Nonetheless, the invasive species issue is not going away. At a minimum, the EPA will have to address how invasive species impact the implementation of existing regulations. TMDLs and Superfund site remediation are just two examples of Agency responsibilities modified by invasive species. EPA will also have to decide what role it will take in managing invasive species. We expect that public and political pressure on the EPA to address invasive species will increase. The petition to regulate ballast water, the exotic species TMDL in San Francisco Bay, and the Invasive Species Executive Order are all harbingers of the future political landscape.

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REFERENCES

Andrews, J. D. 1980. A Review of Introductions of Exotic Oysters and Biological Planning for New Importations. Mar. Fish, Rev., Dec. 1980, 1-11.

Aquatic Nuisance Species Task Force (ANSTF), Risk Assessment and Management Committee. 1996. Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process. Draft final report.

Barber, B. J. 1997. Impacts of Bivalve Introductions on Marine Ecosystems: A Review, Bull. Natl. Res. Inst. Aquacult., Suppl. 3:141-153.

Brown, L.R. and P.B. Moyle. 1997. Invading Species in the Eel River, California: Successes, Failures, and Relationships with Resident Species. Environ. Biol. Fish. 49:271-291.

Bruner, K. A., S. W. Fisher, and P. F. Landrum. 1994. The Role of the Zebra Mussel, *Dreissena polymorpha*, In Contaminant Cycling: II. Zebra mussel Contaminant Accumulation from Algae and Suspended Particles, and Transfer to the Benthic Invertebrate, *Gammarus fasciatus*. J. Great Lakes Res 20:735-750.

Cohen, A. N. and J. T. Carlton. 1995. Nonindigenous Species in a United States Estuary: A Case History of the Ecological and Economic Effects of Biological Invasions in the San Francisco and Delta Region. U. S. Fish and Wildlife Service, Washington, D.C., 246 pages.

Cox, G. W. 1993. Conservation Ecology. William C. Brown Publishers, Dubuque, Iowa. 352 pages.

Daily, G. C., T. Soderqvist, S. Aniyar, K. Arrow, P. Dasgupta, P. Ehrlich, C. Folke, A. Jansson, B.-O. Jansson, N. Kautsky, S. Levin, J. Lubchenco, K. -G. Maler, D. Simpson, D. Starrett, D. Tilman and B. Walker. 2000. The Value of Nature and the Nature of Value. Science 289:395-396.

Daily, Gretchen C., Susan Alexander, Paul R. Ehrlich, Larry Goulder, Jane Lubchenco, Pamela A. Matson, Harold A. Mooney, Sandra Postel, Stephen H. Schneider, David Tilman, George M. Woodwell. 2000. Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. The Ecological Society of America, Issues in Ecology, http://esa.sdsc.edu/daily.htm.

de Groot, D. S. 1927. The California Clapper Rail: Its Nesting Habits, Enemies and Habitat. Condor 29:259-270.

Duncan, C. 1997. Environmental Benefits of Weed Management. Dow-Elanco, Inc., Washington, D.C. (in Westbrooks, 1998).

Endicott, D., R.G. Kreis, Jr., L. Mackelburg, and D. Kandt. 1998. Modeling PCB Bioaccumulation by the Zebra Mussel (*Dreissena polymorpha*) in Saginaw Bay, Lake Huron. J. Great Lakes Res. 24:411-426.

Glassner-Shwayder, K. 2000. Briefing Paper: Great Lakes Nonindigenous Invasive Species. A Product of the Great Lakes Nonindigenous Invasive Species Workshop, October 20-21, 1999

Chicago, Illinois. Sponsored by the U.S. EPA. July 2000.

Harbison, G.R. and S.P. Volovik. 1993. The Ctenophore, *Mnemiopsis leidyi*, in the Black Sea: A Holoplanktonic Organism Transported in the Ballast Water of Ships. Pages 25-36 in "Nonindigenous Estuarine and Marine Organisms (NEMO)", Proc. of the Conference and Workshop, Seattle, Washington, April 1993, U.S. Dept. of Commerce, NOAA, 125 pages.

Haskin, H. H., L. A. Stauber and J. A. Mackin. 1966. *Minchinia nelsoni* n. sp. (Haplosporida, Haplosporidiidae): Causative Agent of the Dealware Bay Oyster Epizootic. Science 153:1414-1415.

Holm, L. J. Pancho, J. Herberger, and D. Plucknett. 1979. A Geographical Atlas of World Weeds. John Wiley & Sons, New York. (in Westbrooks, 1998).

Jacobi, J. D., and J. M. Scott. 1985. An Assessment of the Current Status of Native Upland Habitats and Associated Endangered Species on the Island of Hawaii. Pages 3-22 in C. P. Stone and J. M. Scott (eds). Hawaii's Terrestrial Ecosystems: Preservation and Management. University of Hawaii Cooperative National Park Resources Studies Unit, Honolulu. (in Westbrooks, 1998).

Khalanski M. 1997. Industrial and Ecological Consequences of the Introduction of New Species in Continental Aquatic Ecosystems: The Zebra Mussel and Other Invasive Species. Bulletin Francais de la Peche et de la Pisciculture 0 (344-345): 385-404. (in Pimentel et al., 2000).

Lacey, J.R., C.B. Marlow, and J.R. Lane. 1989. Influence of Spotted Knapweed (*Centaurea maculosa*) on Surface Runoff and Sediment Yield. Weed Tech. 3:627-631.

Lassuy, D. R. 1995. Introduced Species as a Factor in Extinction and Endangerment of Native Fish Species. Amer. Fisheries Soc. Symp. 15:391-396.

Lee, H. et al. 1994. Ecological Risk Assessment of the Marine Sediments at the United Heckathorn Superfund Site. EPA-600/X-94/029. Final Report to Region IX. U.S. Environmental Protection Agency, Washington, D.C.

Lee, H., B. Thompson, and S. Lowe. 1999. Impacts of Nonindigenous Species on Subtidal Benthic Assemblages in the San Francisco Estuary. Draft report reviewed at the December 14, 1999 Region 9 Nonindigenous Species Workshop.

Lee, H., J. Lamberson, K. Welch. 2001. Distribution of Nonindigenous Benthic Species in the Small Estuaries of California, Oregon, and Washington. Presented at EMAP Symposium 2001, Pensacola Beach, Florida, April 2001.

Liebold AM, MacDonald WL, Bergdahl D, Mastro VC. 1995. Invasion by Exotic Forest Pests: A Threat to Forest Ecosystems. Forest Science 41:1-49.

Mack, R., D. Simberloff, W. M. Lonsdale, H. Evans, M. Clout, and F. Bazzaz. 2000. Biotic Invasions: Causes, Epidemiology, Global Consequences and Control. Ecological Applications 10:689-710.

McCarthy, S. A., and F. M. Khambaty. 1994. International Dissemination Of Epidemic *Vibrio cholerae* by Cargo Ship Ballast and Other Nonpotable Waters. Applied Environmental Microbiology 60:2597-2601.

National Research Council. 1996. Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water. National Academy Press, Washington, D.C. 160 pages.

National Research Council. 2000a. Ecological Indicators for the Nation. National Academy Press, Washington, D.C. 198 pages.

National Research Council. 2000b. The Future Role of Pesticides in U.S. Agriculture. Committee on the Future Role of Pesticides in U.S. Agriculture, National Research Council. 332 pages. (http://books.nap.edu/catalog/9598.html?onpi_newsdoc071800).

Office of Technology Assessment. 1993. Harmful Non-Indigenous Species in the United States. OTA-F-65. Office of Technology Assessment, United States Congress. U.S. Government Printing Office.

Pimentel D. 1993. Habitat Factors in New Pest Invasions. Pages 165-181 in Kim KC, McPheron BA, (eds.) Evolution of Insect Pests -- Patterns of Variation. New York: John Wiley & Sons.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and Economic Costs Associated with Non-Indigenous Species in the United States. BioScience 50(1): 53-65.

Pimm, S. L. and J. H. Lawton. 1998. Planning for Biodiversity. Science 279:2068-2069.

Principe, P. 1995. Ecological Benefits Assessment: A Policy-Oriented Alternative To Regional Ecological Risk Assessment. R. Mazaika, R. Lackey, and S. Fraint (eds), Ecological Risk Assessment: Use, Abuse, and Alternatives.

Stevenson, J.C., L.W. Staver, and J.C., Cornwell. 1989. Potomac River *Hydrilla*: Effects of Mowing on Productivity and Nutrient Cycles. Final report to Maryland Department of Natural Resources, 56 pp. (in http://chesapeake.org/pubs/procs/stavstev.html).

Thompson, J. and S. Luoma. 1999. Food Web and Contaminant Effects of An Exotic Bivalve in San Francisco Bay, California. Presented at Coastal Zone 99, San Diego, CA. July 24-30, 1999.

U.S. EPA. 2001. Nonindigenous Species - An Emerging Issue for EPA. Volume 1. Region/ORD Nonindigenous Species Workshop Summaries. EPA report, May 2001. Prepared by Environmental Management Support, Inc. and Henry Lee II.

Vanderploeg, H. and T. Nalepa. 1995. Ecological Impacts of Zebra Mussels in Saginaw Bay. In "ANS Update," Vol. 1, No. 4. Great Lakes Panel on Aquatic Nuisance Species and Great Lakes Commission. Ann Arbor, Michigan. (in Katherine Glassner-Shwayder, 2000)

Wallace, N., J. Leitch, and F. Leistritz. 1992. Economic Impact of Leafy Spurge on North Dakota Wildland. North Dakota Farm Research. 49:9-13. (in The Spread of Invasive Weeds in Western Wildlands: a State of

Biological Emergency, the Governor's Idaho Weed Summit. Boise, Idaho, May 19, 1998; http://www.blm.gov/weeds/BOISUMMI.WPD.html).

Westbrooks, R. 1998. Invasive plants, Changing the Landscape of America: Fact book. Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW), Washington, D.C. 109 pages.

Whisenant, S. 1990. Changing Fire Frequencies on Idaho's Snake River Plains: Ecological and Management Implications. Pages 4-10 in McArthur, E.Romney, S. Smith, and P. Tueller (eds.), Proc. - Symp. on Cheatgrass Invasion, Shrub Die-off and Other Aspects of Shrub Biology and Management. Las Vegas, NV. 1989. For. Serv. Intermountain Res. Stn. Gen. Tech. Rep., INT-2767.

Wiesenborn, W. D. 1996. Saltcedar Impacts on Salinity, Water, Fire Frequency, and Flooding. Saltcedar Management Workshop 3. in "Invasive Species in the Southwest: Tamarix sp. (Salt Cedar); http://www.earlham.edu/~biol/desert/invasive.htm.

Wilcove, D.S., D. Rothstein, J. Dubow; A. Phillips and E. Losos. 1998. Quantifying Threats to Imperiled Species in the United States. Assessing the Relative Importance of Habitat Destruction, Alien Species, Pollution, Overexploitation, and Disease. BioScience 48:607-615.

Wilson, E. O. and F. M. Peter 1988. Biodiversity. National Academy Press, Washington, D. C. 521 pages.

Wolf, E. C. 1993. A Tidewater Place: Portrait of the Willapa Ecosystem. ISBN 0-89886-400-3, The Willapa Alliance, Long Beach, WA.

APPENDICES

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APPENDIX 1: ACTIONS IN THE INVASIVE SPECIES MANAGEMENT PLAN RELATED TO THE EPA

PROPOSED ACTION FROM MANAGEMENT PLAN (OCTOBER 2, 2000)[3]	RELATIONSHIP TO EPA
A. LEADERSHIP	
3. By January 2002, the Council will conduct an evaluation of current legal authorities relevant to invasive species. The evaluation will include an analysis of whether and how existing authorities may be better utilized.	Relates to EPA's legal reviews of using NPDES for ballast water and whether invasives are "pollutants". OGC.
4. Starting in October 2001, each member Department of the Council shall submit an annual written report summarizing their invasive species activities, including a description of their actions to comply with the Order, budget estimates, and steps in implementing the Plan.	Agency's response will be open for review by politicians and public. Response will require coordination across Agency.
7. Beginning with Fiscal Year (FY) 2003, and each year thereafter, the Council will coordinate and provide to the Office of Management and Budget (OMB) a proposed cross-cut budget for Federal agency expenditures concerning invasive species.	Opportunity to increase research efforts in ORD and implementation by Offices and Regions.
10. By February 2001, the Council will convene a working group of agency leads on international agreements relevant to invasive species in order to facilitate communication and the development of U.S. positions that have adequate stakeholder input and are mutually supportive.	Relates to border treaties; OIA, Great Lakes Program, border Regions. Other international agreements?
12. By August 2001, the Council in cooperation with the President's Council on Environmental Quality (CEQ), will prepare and issue guidance to Federal agencies based on the National Environmental Policy Act (**NEPA**) for prevention and control of invasive species.	EPA reviews of environmental assessments (EAs) and environmental impacts statements (EISs) under NEPA - Regions and Office of Federal Activities.
B. PREVENTION	
INTENTIONAL INTRODUCTIONS	
14. By December 2003, the Council will develop a fair, feasible, and risk-based comprehensive screening system for evaluating first-time intentionally introduced non-native species (see items a-e below).	Definition of impairment and implementation of TMDLs under 305(b) and 303(d) for stocked fish. Development of risk-based approach.

[3] The left-hand column are the action items in the final version (January 18, 2001) of the Invasive Species Plan ("Meeting the Invasive Species Challenge") that most directly relate to EPA. The numbers for the action items are those used in the Plan. In some cases the action items are abbreviated. Specific mention of the EPA or EPA regulations are bolded. The right-hand column is our interpretation of some of the ways the action item could impact the EPA and/or the EPA organization potentially affected by the action item.

PROPOSED ACTION FROM MANAGEMENT PLAN (OCTOBER 2, 2000)	RELATIONSHIP TO EPA
15. By 2006, the same Federal agencies (as designated under a-e below) will develop modifications to the screening system or other comparable management measures (i.e., codes of conduct, pre-clearance or compliance agreements) to formulate a realistic and fair phase-in evaluation of those intentional introductions.	
15a. Introduction of non-native biological control organisms for animal pest control within the continental U.S. to complement measures already in place for screening of plant biological control organisms. Lead Departments: USDA, Interior, and **Environmental Protection Agency (EPA).**	OPPTS responsible for microbial pesticides under FIFRA. Regions review under NEPA?
15b. Introduction of all non-native freshwater or terrestrial organisms for any purpose into Hawaii, Puerto Rico, the U.S. Virgin Islands, or U.S. territories or possessions in the Pacific and the Caribbean (because of the vulnerability of insular areas, a separate screening process for those areas is needed). Lead Departments: USDA, Interior and **EPA**, the State of Hawaii, and the Governments of Puerto Rico and the Virgin Islands.	OW and Regions 2 and 9; ORD develop a screening process.
15e. Introduction of non-native aquatic organisms for any purpose (e.g., fish or shellfish stocking, aquarium organisms, aquaculture stock, aquatic plants and biological control agents) within the continental United States. Lead Departments: USDA, Interior, and Commerce, **EPA**, and the Army Corps of Engineers.	Discharges from aquaculture under NPDES. Use of non-native species in water-column or sediment bioassays. Biocontrols under NEPA.
UNINTENTIONAL INTRODUCTIONS	
16. Federal agencies will take the following steps to interdict pathways that are recognized as significant sources for the unintentional introduction of invasive species:	
16a. By July 2001, NOAA, the Coast Guard, Interior, and **EPA** will sponsor research to develop new technologies for ballast water management, because the current method of ballast water management—ballast water exchange—is recognized as only an interim measure to address non-native species introductions.	Ballast water research/validation by ORD, OW, Great Lakes Program, or Regions. Risk assessment approach to ballast water management?
20. By January 2003, the Council will implement a system for evaluating invasive species pathways and will issue a report identifying, describing in reasonable detail, and ranking those pathways that it believes are the most significant. The report will discuss the most useful tools, methods, and monitoring systems for identifying pathways, including emerging or changing pathways, and for intervening and stopping introductions most efficiently.	OW in relation to ballast water, aquaculture discharges, and dredging. ORD conduct risk assessments on pathways.
C. EARLY DETECTION AND RAPID RESPONSE	
EARLY DETECTION	
21. The Council will improve detection and identification of introduced invasive species, recognizing the need for jurisdictional coordination, by taking the following steps:	
21c. By January 2003,USDA, Interior, Commerce, and **EPA** will institute systematic monitoring surveys of locations where introductions of invasive species are most likely to occur (e.g., ports, airports, railroads, highway rights-of-way, trails, utility rights-of-way, logging and construction sites). In	Monitoring of ports could incorporate ongoing compliance monitoring, and/or be a separate program - Region or ORD lead? Research on

PROPOSED ACTION FROM MANAGEMENT PLAN (OCTOBER 2, 2000)	RELATIONSHIP TO EPA
addition, by January 2002, highly vulnerable sites that may warrant more intensive and frequent monitoring than other sites will be identified.	monitoring designs for invasive species (e.g., EMAP approach vs. qualitative surveys).
RAPID RESPONSE	
23c. The Council will review and propose revisions of policies and procedures (i.e., advance approval for quarantine actions, pesticide applications, and other specific control techniques, and interagency agreements that address jurisdictional and budget issues) concerning compliance with Federal (e.g., **Clean Water Act**, **National Environmental Policy Act**, Endangered Species Act) and non-federal regulations that apply to invasive species response actions.	Use of Section 18 under FIFRA for emergency use of pesticides not covered under the registration. OW in terms of water quality criteria.
D. CONTROL AND MANAGEMENT	
26. By February 2002, the Council will identify and, as appropriate, adopt sanitation and exclusion methods for preventing spread of invasive species (e.g., restrictions on use of contaminated soils and fills, cleaning fire-fighting equipment before deployment to new areas, requiring pest-free forage and mulch and weed-free sod, washing of construction equipment, and managing ballast water).	Dredge/fill under 404 of CWA & MPRSA. OW with ballast water management. Superfund remediation?
28. By January 2002, the USDA, in consultation with regional, State, tribal, and local agencies, will develop a proposal for accelerating the development, testing, assessment, transfer, and post-release monitoring of environmentally safe biological control agents and submit the proposal to the Council for review.	Responsibilities under NEPA and FIFRA.
29. By January 2002, **EPA** will develop and provide to the Council a proposal for cooperation with private industry. The proposal will utilize current programs to facilitate development, testing, and training of personnel concerning proper use of environmentally sound pesticides in controlling invasive species populations, consistent with the 1996 **Food Quality Protection Act** (P.L.140-170) and the Federal Insecticide, Fungicide and Rodenticide Act (**FIFRA**).	OPPTS responsibilities under FIFRA and Food Quality Protection Act.
32. By January 2003, the Council will develop and guidance [sic] for ranking the priority of invasive species control projects at local, regional, and ecosystem-based levels.	Development of risk assessment approaches.
E. RESTORATION	
35. By July 2002, the Council will develop and issue recommendations, guidelines and monitoring procedures for Federal land and water management agencies to use, where feasible, in restoration activities. Among other things, these will:	
35a. Address restoration programs mandated by law (e.g., natural disasters, oil and chemical spills, and acid mine drainage).	Restoration under Superfund including phytoremediation. Wetland restoration under mitigation banking (Section 404).
35b. Identify the appropriate uses of native and desirable non-native species and encourage management practices that promote regeneration of native species.	Restoration under Superfund including phytoremediation. Wetland restoration under mitigation banking

PROPOSED ACTION FROM MANAGEMENT PLAN (OCTOBER 2, 2000)	RELATIONSHIP TO EPA
	(Section 404).
35c. Develop and describe the best available techniques for restoring habitats such as arid and aquatic environments and highly eroded or disturbed sites, and identify research needs for technique development.	Wetland restoration under mitigation banking (Section 404). Other aquatic habitats? ORD develop approaches.
F. INTERNATIONAL COOPERATION	
38. By December 2001, the Council will outline an approach to a North American invasive species strategy, to be built upon existing tripartite agreements and regional organizations, and initiate discussions with Canada and Mexico for further development and adoption.	Article IV of the Boundary Waters Treaty with Canada addresses aquatic invasive species. Additional obligations under the US-Canada Great Lakes Water Quality Agreement (GLWQA)? Other border treaties?
G. RESEARCH	
43. By July 2001, the Council, in coordination with FICMNEW, SI, the ANSTF, and CENR, will prepare a catalog of existing aquatic and terrestrial control methods — The catalog should include the following:	
43a. Validation methods to measure and report removal efficiency, cost-effectiveness, safety, and practicality under real-world conditions.	Ballast water treatment research, OPPTS involved with safety of pesticides.
43b. Treatments and effectiveness measurement protocols.	Involvement of ORD and Environmental Technology Verification (ETV) program, in particular with ballast water treatment.
45. By July 2002, the Council, SI, and NSF, utilizing input from CENR, will establish and coordinate a long- and short-term research capacity ranging from basic to applied research on invasive species. This initiative will build on existing efforts that reflect a range of perspectives and program approaches. It will address research, monitoring, information sharing (including mapping), assessment, control, and restoration. It will identify personnel and resources needed to sustain fundamental research and tactical or field-level scientific support which include:	ORD can contribute especially in monitoring design & interpretation, effects on ecosystem functioning, development of risk assessment approaches, and effects on pollutant fate and effects.
45a. Improvement of Federal agency core capabilities.	Effects on in-house ORD efforts and resource allocations.
45b. Enhancement of current competitive grants programs and mechanisms for cooperative support of research by public and private universities, Federal and State governments, and the private sector to complement core research capabilities.	ORD STAR program. Program Office or Regional projects?
46. As part of the cross-cut budget proposal for FY 2003, the Council will include an initiative to adequately fund Federal invasive species research programs. ... The proposal will address research issues such as:	Primarily ORD.
46a. Determine how and to what extent invasive species affect populations of native species, endangered and threatened species, habitats, animal health, human health, and native species biodiversity.	Relation to development & interpretation of biocriteria. Protection of endangered species. Incorporation of effects of invasive

PROPOSED ACTION FROM MANAGEMENT PLAN (OCTOBER 2, 2000)	RELATIONSHIP TO EPA
	species in risk assessment of other anthropogenic stressors.
46d. Determine how and to what extent invasive species alter ecosystem (e.g., water quality, hydrology, nutrient cycling, and disturbance regimes such as fire cycles), agricultural, economic, and social processes.	Key to understanding effects of invasives on non-point runoff and TMDLs - OW and ORD.
46e. Develop and test monitoring and control protocols, methods, tools, and strategies to support the prevention of introduction and spread, rapid response, restoration and containment strategies, including the evaluation of impacts from management activities.	Develop/validate control mechanisms for ballast water. Ecological and human health effects of control measures (e.g., discharge of biocides, effects of pesticides on non-target species). Validation conducted under ETV.

PROPOSED ACTION FROM MANAGEMENT PLAN (OCTOBER 2, 2000)	RELATIONSHIP TO EPA
H. INFORMATION MANAGEMENT	
50. By November 2001, the Council will develop and secure implementation of a memorandum of understanding among appropriate Federal Departments to establish an invasive species assessment and monitoring network comprised of on-the-ground managers of Federal invasive species programs and appropriate technical specialists.	Incorporation of compliance monitoring and research monitoring into the monitoring network. OW, Regions, and ORD.
51. By January 2002, Interior, USDA, Commerce, **EPA** and U.S. Army Corps of Engineers will develop guidance for managing information concerning invasive species in aquatic and terrestrial environments.	Office of Environmental Information (OEI); interface with STORET and other EPA databases.
51a. Current and emerging technologies for information collection (e.g., GIS and remote sensing) and data analysis and dissemination, including lower-cost information tools for wide distribution.	Research on remote sensing. OEI?
51b. Standard protocols for information collection and sharing, including taxonomy, identification, inventory and mapping, monitoring, and assessments of invasive species populations.	ORD and OW input into protocols
51c. Most effective means and appropriate contacts - including those of the Council - for sharing information with local, State, tribal, Federal, and international agencies, non-governmental organizations, private citizens, and other stakeholders, that link to systems currently underway.	Use of outreach networks developed by Regions and Program Offices, especially to States and the regulated stakeholders.
I. EDUCATION AND PUBLIC AWARENESS	
56. By July 2001, the Council will coordinate development and implementation of a national public awareness campaign, emphasizing public and private partnerships.	Use of outreach networks developed by Regions and Program Offices with the public. OEI.

APPENDIX 2: EFFECTS OF INVASIVE SPECIES ON ACHIEVING GPRA GOALS AND OBJECTIVES

GOAL AND OBJECTIVE	POTENTIAL EFFECTS OF INVASIVE SPECIES [4]
GOAL 1 - CLEAN AIR	
Objective 1 - NAAQS for ozone and PM.	Regional and local effects on PM levels resulting from increased fire frequency due to flammable exotic weeds.
Goal 2 - Clean and Safe Waters	
Objective 1, Subobjective 1.1 - 95 percent of drinking water systems will meet 1994 health-based standards.	Harmful algal blooms (HABs) and macrophytes resulting in taste & odor problems.
Objective 1, Subobjective 1.5 - Increase in waters attaining the designated uses protecting the consumption of fish and shellfish.	Shellfish contamination and closures resulting from harmful algal blooms (HABs) seeded by ballast water discharges. Changes in food web structure increasing trophic transport of contaminants to fish and shellfish.
Objective 1, Subobjective 1.6 - Exposure to microbial and other forms of contamination in waters used for recreation will be reduced.	Introduction of cholera and other water-borne pathogens through ballast water discharges.
Objective 2, Subobjective 2.1 - Restore and protect watersheds so that 75 percent of waters support healthy watersheds.	Terrestrial and wetland invaders degrading watershed functions, including pollutant loadings into surface and estuarine waters. Water quality standards and designated uses impaired directly by wetland or aquatic invaders.
Objective 2, Subobjective 2.2 - Net increase of 100,000 acres of wetlands.	Invasive wetland plants reducing existing native wetlands. Effects of invasions on the success of wetland restoration and implications on wetland banking.
Objective 2, Subobjective 2.3 - Provide means to identify, assess, and manage aquatic stressors (ORD has lead).	Requirements for more stringent controls on other stressors because of reductions in the "assimilative capacity" of native species. Invasive effects on critical habitat types and functions. Effects of invasives on fate and effects of pollutants.
Objective 2, Subobjective 2.4 - Restore and maintain integrity of Chesapeake Bay, Gulf of Mexico and National Estuary Program ecosystems.	Effects on species composition, productivity, trophic composition, and sustainability of the ecological resources of Chesapeake Bay, Gulf of Mexico, and NEP estuaries.
GOAL AND OBJECTIVE	**POTENTIAL EFFECTS OF INVASIVE SPECIES**

4 This table presents our assessment of the GPRA Goals and Objectives impacted by invasive species. The potential effects on the GPRA Goals and Objectives are presented as examples; there may be additional effects. The exact nature and extent of the impact of invasive species on the performance measures for an Objective will vary depending upon a suite of factors, such as the specific invasive species, ecosystem type, and regional characteristics (e.g., effects of increased fire on air quality more important in arid West than on East coast).

Objective 3, Subobjective 3.2 - Nonpoint source loadings (especially sediment and nutrient loads) will be reduced.	By altering erosion, deposition, and nutrient dynamics, invasive terrestrial and wetland plants can alter loadings into surface and estuarine waters.
Goal 3 - Safe Food	
Objective 1 -Reduce agricultural pesticide risk.	Continued introduction of new exotic pests requires increased use of existing pesticides and/or development of new pesticides. Registration of biopesticides as biocontrols for exotic pests.
Goal 4 - Pollution Prevention and Reducing Risk	
Objective 1 - Reduce public and ecosystem exposure to pesticides.	Increased use of existing and new pesticides to control exotics in urban settings and homes increases public's exposure. Use of these pesticides increases ecosystem exposures via runoff and drift. Exposure from pesticides used to manage invasives in public lands.
Objective 5 - Improve pollution prevention strategies, tools, approaches.	A key method of reducing pesticide exposure is to prevent the introduction of new exotic pests, many of which require higher concentrations of existing pesticides or new pesticides. Rapid response to new introductions.
Goal 5 - Better Waste Management, Restoration of Contaminated Sites, and Emergency Response	
Objective 1 - Reduce or control risks to human health.	Limitations on using exotic species in phytoremediation and other restoration activities. Potential for remedial actions to promote spread of invasive species through the creation of disturbed habitat susceptible to invasion. Question whether sites need to be restored to "native" conditions.
Goal 6 - Reduction of Global and Cross-Border Environmental Risks	
Objective 1 - Reduce transboundary threats: North American ecosystems.	Transport of invasive species is covered under Boundary Water Treaty with Canada, which impacts North Dakota water diversion projects. Effects on other boundary agreements (e.g., Great Lakes and Puget Sound).
Objective 2 - Climate change.	Invasive plants can dramatically alter patterns and rates of carbon sequestration while increased fire frequency increases CO_2 inputs. Climate change is likely to increase invasion rate and spread of exotic species, including pathogens and their vectors.
Objective 4 - Protect public health and ecosystems from persistent toxics.	Effects of invasives increasing runoff and hence loadings of pollutants. By altering structure of aquatic food webs, invasive species can alter the fate of persistent toxics, potentially increasing concentrations in fish, shellfish, and wildlife. Requirements for more stringent controls on toxics because of reductions in the "assimilative capacity" of native species.
Goal 7 - Expansion of American's Right to Know	
Objective 1 - Increase quantity/quality of education, outreach, data availability.	In coordination with the Invasive Species Council, the EPA could use its existing infrastructure to educate state agencies, tribes, the public, and the regulated community in the areas related to the Agency's mission (e.g., dredge disposal, use of exotic species in bioassays and phytoremediation, NPDES discharges, NEPA).

GOAL AND OBJECTIVE	POTENTIAL EFFECTS OF INVASIVE SPECIES
Goal 8 - Sound Science	
Objective 1 - Ecosystem assessment and restoration.	EMAP and other programs establish baselines for nonindigenous species as well as relative impact on aquatic resources. Develop biological indicators incorporating presence and effects of invasive species. Research on the effects of invasives on the fate of pollutants and on effects of anthropogenic stressors on promoting invasions.
Objective 3 - Emerging risks.	Extramural research on nonindigenous species through STAR program.
Objective 4 - Pollution prevention and new technology.	Validate effectiveness of ballast water treatment techniques through inhouse research and/or extramural programs (e.g., ETV or STAR).
Objective 8 - Regional enhancement of ability to quantify environmental outcomes.	Develop specific regional information to allow Regions to incorporate invasive species effects when evaluating relative ecological risks and effectiveness of management actions.
Goal 9 - Credible Deterrence to Pollution	Involvement of the Agency in the regulation of invasive species will increase demands on enforcement and compliance monitoring. In particular, NEPA, NPDES, TMDLs, and FIFRA have been suggested as regulatory “hooks” to manage invasive species.

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APPENDIX 3: INVASIVE SPECIES RESEARCH NEEDS

The research needs presented here relate to EPA's mission to a greater or lesser extent, research obviously outside of EPA's mission (e.g., methods to monitor agricultural pests) is not included. Listing of these topics does not imply that EPA should, or has the resources, to address all these topics. Several of these research topics could be integrated into existing programs while others would require a targeted research effort.

I. BALLAST WATER AND OTHER AQUATIC VECTORS

A. Ballast Water Exchange and Alternative Treatment Systems

Conduct risk analyses to determine what type (e.g., size, taxonomic class) of organisms need to be removed from ballast water to protect human health and/or ecological systems.

Determine effectiveness of mid-ocean ballast water exchange in terms of removal of various types of organisms. Evaluate how effectiveness varies with such factors as duration of the voyage, size of ship, sediment load in ballast tanks, "no ballast on board" (NBOB) vessels, etc.

Evaluate the effectiveness and practicality of ballast water treatments systems. Potential treatments include: 1) providing clean ballast water initially (e.g., freshwater); 2) filtration (e.g., centrifugation); 3) biocides; 4) UV; 5) heat; and 6) shoreside treatment system including discharge into sewage systems. Evaluation needs to include costs, environmental impacts, and safety.

Develop diagnostic chemical or physical measures to determine whether a ship has exchanged its coastal ballast water with ocean water.

B. Exposure & Effects of Ballast Water

Evaluate whether ballast water discharges promote harmful algal blooms (HABs) by releasing spores of toxic dinoflagellates or by other mechanisms.

Evaluate the link between ballast water discharges and outbreaks of cholera and other water-borne pathogens.

Determine how effective ballast water exchange and/or alternative treatment processes need to be to adequately protect against the establishment of nonindigenous species (e.g., is 100 percent removal necessary or is 95 percent sufficiently protective?).

C. Other Aquatic Vectors

Evaluate the role of the fouling organisms on hulls of ships and the aquarium, bait, and live seafood industries as vectors for introductions.

II. BIOLOGY AND LIFE HISTORIES OF NONINDIGENOUS SPECIES

Conduct life-history and physiological studies on a suite of aquatic and wetland exotic species. Focus on identifying critical life history stages for control (e.g., sea lamprey), predicting impacts on ecosystem structure and function, and elucidating common traits of successful invaders.

Evaluate the potential for hybridization between nonindigenous native species. Predict the impacts of hybridization on the sustainability of the native populations.

III. INVASION THEORY AND ECOSYSTEM VULNERABILITY

Evaluate the relationship of anthropogenic stressors (e.g., pollutants, sediment runoff, water diversion) and the susceptibility of aquatic ecosystems to invasions.

Develop the basic biology and the models to predict which nonindigenous species presently at low densities will become invasive (e.g., changes in life history structure to predict population explosions).

Evaluate the role of increased nitrogen levels on promoting invasive weeds. Determine the role of atmospheric inputs in the spread of invasive weeds.

Develop the data/models to predict the types of impacts that "keystone" invaders have on the structure and function of different ecosystem types, such as filter-feeding bivalves on freshwater and estuarine ecosystems.

Develop methods and the data to predict the likely sources and vectors for invasions into different ecosystems by biogeographical regions. Include regional studies of shipping patterns to determine the amount and sources of ballast water into different water bodies.

Evaluate the ecological impacts of nonindigenous species on Hawaii, other island ecosystems, and other functionally isolated systems.

IV. ECOSYSTEM STATUS AND MONITORING

Using both available data and new field data, quantify the extent and nature of invasions in different aquatic habitat types by biogeographical regions. Evaluate both at fine and coarse scales (e.g., within habitat, within region).

Develop monitoring approaches for detecting the early presence of new exotic species, including use of qualitative surveys, data from compliance monitoring, and observations from stakeholders (e.g., power plant operators). Develop strategies and networks to integrate these various approaches.

Evaluate use of genetic markers as a rapid detection method for the larval stages of aquatic nonindigenous species that have not yet established obvious adult populations.

Develop and validate remote sensing technologies to monitor for nonindigenous plants in terrestrial and wetland ecosystems (e.g., use of hyperspectral analysis).

Address the sufficiency/accuracy of taxonomic identifications in research and compliance monitoring programs, including QA/QC strategies and requirements.

V. BIOCRITERIA AND CRITICAL HABITATS

Develop biocriteria reflective of the present and potential future ecological impacts of nonindigenous species. Develop both structural and functional metrics.

Develop biocriteria or other methods to evaluate the total impact of "desirable" nonindigenous species (e.g., stocked fish)

Develop biocriteria or other methods to evaluate the cumulative impacts from multiple "benign" nonindigenous species.

Evaluate the impact of nonindigenous species on "critical habitats", such as coral reefs and submerged aquatic vegetation (SAV). Develop models to predict the future changes in the area and fragmentation of critical habitats in response to invasions.

VI. WILDLIFE

Evaluate the direct (predation, competition) and indirect (habitat alteration) effects of nonindigenous species on wildlife populations. Incorporate habitat-related impacts into spatially-explicit population models.

Evaluate the role of exotic pathogens on wildlife populations, in particular amphibians and fish populations. Evaluate intermediate hosts and the vectors transporting these pathogens both within and among biogeographical regions.

VII. WETLAND, RIPARIAN, AND UPLAND REMEDIATION

Develop methods for the construction and maintenance of wetlands, riparian zones, and upland habitats that minimize invasions by exotic weeds.

Develop methods and guidance for the control of specific wetland invaders (e.g., *Spartina*) and upland invaders. The analysis should include efficacy, cost, and impacts on non-target species.

Evaluate the risk of remediated sites becoming invasion "hot spots" for neighboring habitats.

Evaluate alternatives to exotic species for phytoremediation in aquatic, wetland, and terrestrial habitats. When no viable alternative exists, develop guidance to minimize the risks of the spread of exotic species.

VIII. NUTRIENT CYCLES AND NON-POINT RUNOFF

Evaluate the effects of invasive terrestrial plants on the hydrologic cycle and the runoff of clean sediments, nutrients, and toxic pollutants. Include changes in fire frequency/intensity as one of the parameters.

Develop models incorporating the effects of exotic weeds on TMDLs for nutrients, pollutants, and clean sediments. For nutrients, incorporate both changes in runoff and changes in the nutrient cycle (e.g., nitrogen fixation).

IX. POLLUTANT DYNAMICS IN AQUATIC SYSTEMS

Evaluate/model how invasive aquatic species alter the flux and fate of pollutants in freshwater and estuarine ecosystems. The models should include both direct effects, such as filtration of contaminated particles from the water column, and indirect effects, such as alterations in food webs.

X. RISK ASSESSMENT METHODOLOGIES

Develop methods to predict the future risks associated with nonindigenous species, including both the potential expansion of the nonindigenous species populations within a habitat and the spread of the nonindigenous species to neighboring habitats.

Conduct comparative risk assessments evaluating the relative impact of invasions of nonindigenous species versus other anthropogenic stressors. One goal would be to rank the relative impacts of stressors on key assessment endpoints.

Develop methods to compare the ecological and human health risks associated with control measures (e.g., pesticides, controlled burns) versus the direct impacts of the invasives.

Develop strategies for the incorporation of positive effects of nonindigenous species (e.g., recreation, soil stabilization) into risk assessments.

XI. HUMAN HEALTH - DIRECT AND INDIRECT

Evaluate the role of ballast water discharges as a dispersal vector for water-borne pathogens such as cholera.

Evaluate/model the human exposure, and the associated health risks, from pesticides used to control invasive species in both agricultural and non-agricultural settings. Include analysis of sensitive sub-groups (e.g., children).

Evaluate the direct and indirect roles of water and sediment quality in the spread of exotic diseases or their vectors (e.g., loss of frogs allowing increases in mosquitos, which in turn spread West Nile virus)

XII. SOCIOECONOMIC IMPACTS

Estimate the direct and indirect economic costs of nonindigenous species on non-agricultural systems, especially as they relate to EPA's mission.

Develop innovative methods to educate the public and EPA's stakeholder groups (e.g., dischargers) on the need for controlling the spread of nonindigenous species.