to exclude a new crop plant depends on the following factors:

- the damage that would be caused if a useful plant were excluded
- the damage that would be caused if a weed were allowed in
- the background probability that a plant would become a weed (the base rate)
- the accuracy of the system that predicts whether the plant will be a weed

The decision-theory approach to building invasion risk assessments into policy decisions holds promise but will demand more knowledge than we currently have on invasion epidemiology, particularly information on the benefits of useful species (not normally considered or questioned in invasion risk assessment) and information on how the base rate varies with type and location of introduction.

SEE ALSO THE FOLLOWING ARTICLES
Agreements, International / Invasive Meltdown / Invasibility of Communities and Ecosystems / Invasion Economics / Lag Times / Propagule Pressure

REFERENCES

RIVERS

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Rivers are centers of aquatic biodiversity but have been enormously affected by invasive species. Some of the most widely introduced species in rivers are fishes such as salmonids in headwater streams or carps in large rivers, but many invertebrates (e.g., zebra mussels, various crayfish, and amphipods) and plants (e.g., water hyacinths, Eurasian milfoils) have also become widespread. The documented ecological impacts of invasive species in rivers are enormous, and occur from the individual to the ecosystem level. Although environmental degradation facilitates invasion, even protected ecosystems such as headwater streams are not free from invasions (e.g., salmonids). The “island nature” of river basins for many freshwater organisms underlines the need for prevention and early eradication of new introductions. Preserving or restoring the natural flow regime usually favors native species and is essential to reduce the abundance and impacts of invasive species.

RIVERS AS ECOSYSTEMS

Rivers and lakes occupy only about 0.8 percent of the Earth’s surface and hold only 0.3 percent of its freshwater (most of it in glaciers, snow, or underground), which in turn is only 2.5 percent of the total water availability (the rest is seawater). The importance of rivers is, however, huge in terms of biodiversity and human services. Freshwater ecosystems have about 2.4 percent of the world’s animal and plant species and have almost as many described fish species as the sea (about 12,000 versus 16,000), even though oceans occupy 70 percent of the Earth’s surface. Many freshwater organisms, mostly those that cannot tolerate seawater or those without dispersing stages such as many insects with aquatic larvae and flying adults, cannot move naturally among river basins. This makes watersheds strong natural barriers and explains the high frequency of endemic species in river basins.

Rivers provide major services to human society, including potable water, irrigation for agriculture, fisheries, transport, and hydroelectric energy. For this reason, freshwater ecosystems are among the most altered and threatened of the world and have suffered many extinctions and many species introductions. Most large river basins are heavily regulated by either dams or water abstraction, have been polluted by fertilizers and chemical wastes, and have been interconnected to facilitate transport or water transfer. Most of these human activities facilitate invasions of freshwater organisms, which are introduced either intentionally or as byproducts of other human activities (e.g., shipping). As a result, riverine ecosystems are increasingly being invaded by alien species to the point where alien flora and fauna can dominate these systems. Alien trout (Salmonidae) and invertebrates, such as New Zealand mud snails (Potamopyrgus antipodarum), may be very abundant in headwaters. In large rivers, abundant alien species worldwide include...
Especially the red-eared slider (*Trachemys scripta elegans*); mammals such as the American mink (*Neovison vison*), muskrat (*Ondatra zibethicus*), and nutria or coypu (*Myocastor coypus*); and waterfowl such as Canada geese (*Branta canadensis*) and mute swans (*Cygnus olor*).

### Invertebrates

The best-known invertebrate river invaders are mollusks and crustaceans. Among the mollusks with strongest effects are the zebra mussel (*Dreissena polymorpha*) and the Asian clam (*Corbicula fluminea*), both of which threaten native mollusks worldwide, largely through direct displacement. They have the potential to alter, at least locally, riverine food webs through their actions as filter feeders. Among crustaceans, crayfish (e.g., *Procambarus clarkii*; Fig. 2) are among the best documented as invaders, but other species ranging from amphipods to crabs have had impacts. One such problem species is the Chinese mitten crab (*Eriocheir sinensis*), which lives as an adult in estuaries but migrates upstream into rivers in huge numbers to breed, clogging water intake structures and causing other damage.

### Parasites

Parasites are little appreciated as invaders in rivers, yet their effects can be dramatic. The introduction of crayfish plague (*Aphanomyces astaci*) into Europe from North America, by North American crayfish, dramatically reduced Europe’s native crayfish populations. Likewise, the introduction of whirling disease by brown trout from Europe has reduced native trout populations in some North American rivers, and the introduction of tapeworms from Asian grass carp has caused problems with endangered riverine cyprinids in the western United States.
dispersal. Species introduced into headwater systems likewise can spread downstream rapidly.

The lower reaches of rivers and streams in developed countries of the northern hemisphere harbor more invasive species than do headwater streams or tropical rivers. This probably reflects more frequent introductions, more intense sampling, and more environmental degradation of the former rather than a higher intrinsic invasibility. Evidence suggests that most river systems can be invaded. For example, in South America, tropical rivers with diverse fish faunas have been invaded by tilapia species and African catfish (Clarias gariepinus). Near-pristine headwater streams throughout the world have likewise been successfully invaded by salmonid fishes. In fact, there is growing evidence to suggest that, in temperate areas, some of the most invaded rivers are those with rich native faunas. Invasion success is also increased by habitat degradation. For example, the Colorado River in North America is one of the most altered rivers in the world, with its waters being diverted, stored in reservoirs, or highly polluted. As a result, most of the native aquatic species are gone, and the river is dominated by alien fishes, invertebrates, and plants, including dense growths of salt cedars in the riparian zone. Many of this river’s freshwater invaders, such as common carp, western mosquitofish (Gambusia affinis), tilapia (Oreochromis spp.), zebra mussels, bullfrogs, and water hyacinth, are also very resistant to pollution. Not surprisingly, species such as these increasingly have global distributions.

INVASIBILITY OF RIVERS

The linear nature, large size, and diverse habitats of rivers make them extremely vulnerable to introductions of alien species and to their spread. The lower reaches often end in estuaries or large cities, where shipping and large numbers of people increase the frequency of introductions. The rivers then become convenient corridors for

Plants

Aquatic and riparian plants can cause major changes to river ecosystems by reducing flow through stream channels, shading large areas, and dominating riparian ecosystems. They often create habitats favored by other nonnative species, especially snails and fishes, thus reducing local species diversity. Among the best-known global invasive plant species are water hyacinth (Eichhornia crassipes), Eurasian watermilfoil (Myriophyllum spicatum), hydrilla (Hydrilla verticillata), Eurasian watermilfoil (Myriophyllum spicatum), the ferns Salvinia molesta and Azolla filiculoides (Fig. 3), and the giant reed Arundo donax. Ecosystem changes caused by alien plants include reduction of stream flows by salt cedars (Tamarix spp. in North America (Fig. 4), nitrogen soil enrichment by black locust (Robinia pseudoacacia), increased erosion rates by Impatiens glandulifera, and alteration of the light regime and biogeochemical cycles by floating plants such as water hyacinth or Salvinia molesta. These floating plants can also impede navigation in rivers.
Many freshwater invaders are often first introduced into reservoirs behind dams on rivers; they typically are species that thrive in lakes or in backwater habitats of rivers. Thus, widespread aliens such as the common carp, mosquitofishes (G. affinis and G. holbrooki), largemouth bass (Micropterus salmoides), tilapia, or water hyacinth can become well established in reservoirs, which then serve as a source for continual downstream colonization, even if the species are not particularly well adapted to riverine habitats. Rivers with highly regulated flows, however, can favor these introduced species, which can then displace native species. The invasive success of introduced fish such as the rainbow trout (Oncorhynchus mykiss) has been shown to depend on the matching of the hydrological regime with critical reproductive events such as fry emergence.

MANAGEMENT OF INVASIVE SPECIES IN RIVERS

The management of invasive species in rivers is similar to that in other systems, with prevention of new introductions and spread of harmful species having the highest priority. Specific management measures emerge from the properties of freshwater ecosystems and their invaders. Avoiding or reversing environmental degradation is essential because many invaders thrive in altered habitats. Preserving or restoring the natural flow regime will often benefit native species adapted to the regime, especially for reproduction, and will discourage alien species, although it will rarely eliminate them entirely. In a regulated river, for example, prescribed floods can be useful to reduce the populations of introduced species such as largemouth bass, mosquitofish, and many invasive plants, especially if used in conjunction with more direct control measures.

In some instances, dams may be useful barriers to prevent upstream spread of invasive species, although more typically they are the source of invasions downstream. For some dams, screens have been developed on outlets to prevent alien fish from escaping downstream. Eradication of unwanted fishes (usually common carp) and plants using toxicants and other means has been tried in a number of rivers, but it is rarely successful because some individuals usually manage to escape in the complex habitats present in rivers.

SEE ALSO THE FOLLOWING ARTICLES
Carp, Common / Crayfish / Freshwater Plants and Seaweeds / Hydrology / Invasibility, of Communities and Ecosystems / Mammals, Aquatic / Water Hyacinth / Zebra Mussel

FURTHER READING

RODENTS (OTHER)

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Although rats have received the most attention, other rodent species have significantly affected native ecosystems, communities, and species. By far the greatest impacts have been on islands. Those rodents that change entire ecosystems, generally by affecting the physical structure of the habitat (ecosystem engineers), have caused the most far-reaching changes. These include three aquatic species widely introduced as fur-bearers: nutria (Myocaster coypus), North American beavers (Castor canadensis), and muskrats (Ondatra zibethicus). Many other rodents have been introduced and have persisted; some have spread. Often, damage to human enterprises (e.g., agriculture) is described, but reports of ecological damage are not as common. The house mouse (Mus musculus) and the North American gray squirrel (Sciurus carolinensis) are the most important ecologically.

AQUATIC FUR BEARERS

North American Beavers

The North American beaver (Fig. 1A), by virtue of its tree-cutting and damming activities, is the paradigmatic ecosystem engineer, transforming forests into wetlands, changing stream flows, and modifying nutrient dynamics and decomposition. It has been successfully introduced to Tierra del Fuego, Kodiak Island, the Queen Charlotte Islands, Anticosti Island, Finland, and Russia.