CONTROL AND ERADICATION OF INVASIVE AQUATIC INVERTEBRATES

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Summary

Invasive species have been recognized as serious threats to aquatic biological diversity and may cause significant economic losses. Vector management is the most effective strategy for reducing the risk of transport and introduction of exotic biota, and the best

precautionary approach. Eradication and control strategies generally target exotic species that have negative economic impacts. We examine case histories of aquatic and marine invasive invertebrates and review the actions taken for their control or eradication, and the outcomes.

1. Introduction

Marine bioinvasions have become an issue of global concern following the damage caused by the Eurasian zebra and quagga mussels (*Dreissena polymorpha, D. bugensis*) in the North American Great Lakes and the Mississippi River system, the Northern Pacific toxic dinoflagellates, seastar (*Asterias amurensis*) and *Undaria* seaweed in Australia, and the American comb jelly (*Mnemiopsis leidyi*) in the Black Sea. It is now widely recognized that bioinvasions into freshwater, estuarine, and marine habitats may adversely affect biodiversity, alter the structure of host ecosystems and cause significant economic losses.

Freshwater, estuarine, and coastal environments are among the most invaded ecosystems, as well as the most altered. While exotic species have been charged with causing major changes in aquatic ecosystems, including decline and decimation of native biota, the invaded environment has typically already suffered widespread disruption by human activity: the rapid increase in human population density and urbanization has brought about coastal development, increased levels of agricultural runoff and industrial wastes, unsustainable fishing practices and mariculture. Empirical evidence suggests that success of invasive species increases with declining indigenous biodiversity, and that larger, older, more complex biosystems with strongly-interacting species-rich communities are more resistant to invasion, so that the most effective protection against invasive species would appear to be the conservation of a diverse and healthy assemblage of native species.

2. Vector Management: An Ounce of Prevention Is Worth a Pound of Cure

Vector management is the most effective control strategy for preventing introduction of exotic biota as an unprecedented number of organisms are transported worldwide. Shipping is considered the largest single vector for the movement of exotic marine species across the globe, in hull fouling and in ballast water and sediments. Other possible vectors are intentional and unintentional mariculture, bait and pet-trade species transfers, and cross-canal movement.

Hull fouling has been greatly reduced with the introduction of organotin paints in the 1970s. The xenobiotic paints induce imposex, and may decimate biota in and near ports. The use of organotins has been banned in many countries, and alternative, environmentally accepted methods are being sought.

The urgent need to control ballast-mediated bioinvasions prompted the maritime industry and the legislators to adopt open-ocean ballast water exchange (OOE) to reduce the risk of ballast-mediated bioinvasions. However, following reservations raised concerning the effectiveness of removal of harmful organisms, and ship safety constraints relating to OOE, the Ballast Water Working Group, Marine Environment

Protection Committee (MEPC) of the International Maritime Organization (IMO) agreed that "Ballast Water Exchange should be regarded as an interim solution and that the aim is to produce safe and more effective alternative ballast water treatment options that will replace Ballast Water Exchange" (MEPC 46/3 2000). Significant research and development efforts are underway, aimed at developing a more complete solution. A number of treatment options, based on technologies currently in use for industrial or domestic water treatment, including heating, filtration, UV irradiation, and chemical biocides, have potential to either eliminate or significantly reduce the number of organisms present in ballast.

Translocations of fish and shellfish for aquaculture and mariculture purposes have increased dramatically since the 1950s. The mass transfer of the commercially valuable species may have negative ecological and genetic effects on native ecosystems resulting from the accidental release of the target species that might genetically impact or outcompete native species, or the inadvertent introduction of harmful organisms associated with the target species. The International Council for the Exploration of the Sea (ICES) has attempted to address these concerns and has published a *Code of Practice on the Introductions and Transfers of Marine Organisms* in 1994 that recommended procedures and practices that aim to diminish the risks and effects of intentional transfer of aquatic organisms. The Code set forth recommendations referring to the preintroduction and introduction procedures, the release of genetically modified organisms, and the prevention of unauthorized introductions. Implementation of the Code represents the best form of responsible precautionary approach in the intentional import of exotic species.

3. Control and Eradication Efforts

Eradication and control strategies generally target "pest" or "nuisance" invasive species—terms used to identify exotic species that have negative economic impacts. The economic cost of some aquatic exotic species is significant: estimated costs of damage caused by and control of the zebra mussel, the Asiatic clam, and the European green crab are US$4.4 billion in the USA alone.

Most invasive species become accommodated in existing assemblages through niche shifts and other mechanisms, never disrupting their new ecosystem, nor turning into major pests. However, given the complexity of the aquatic ecosystem, the likelihood of correctly predicting whether or when an exotic species will become a pest is low. Past behavior of an exotic species may be a poor predictor of its future potential for explosive growth, range extension and ecological effects, and its lag phase may change when some aspect of the biotic or abiotic environment is altered. It has been suggested that when an exotic species is identified at an early stage in the colonization, has limited spatial distribution, and there is an opportunity to eradicate it with acceptable environmental consequences, it should be promptly exterminated. Eradication methods and technologies need not then be highly specific since their possible damage to nontarget species are limited to a small area. Once the exotic organism reproduces successfully or is widely dispersed, eradication becomes impossible and long-term control becomes the preferred strategy to reduce the population to an economically or ecologically acceptable level and to maintain it at that level.

Control techniques need to have higher specificity to reduce impacts on nontarget species, long-term effects on the environment, and achieve cost-effectiveness and ease of use. The proactive integrated pest management (IPM) approach combines early detection, risk evaluation, and control options. Three management technologies are generally applied to control pest species: mechanical/physical, chemical, and biological.

It has been suggested that biological control, long used in terrestrial systems, involving the introduction of a predator, parasite, or pathogen, or genetic manipulation, may present an option for marine pests management, in particular invasive species. The use of egg predators and parasitic rhizocephalan castrators, considered important regulators of host population density, is favored. However, recent studies raised concerns over their efficacy, host-specificity, and safety, and further research is required.

We examine histories of aquatic and marine invasive invertebrates and review the attempts made and actions taken for control or eradication, and their outcome.

4. Case Histories

4.1. Ctenophora: The Comb Jelly That Ate A Sea, *Mnemiopsis leidyi*

The Atlantic comb jelly (*Mnemiopsis leidyi*) has drastically affected the ecology and productivity of the Black Sea, since its introduction, probably in ballast water, in the early 1980s. It has since spread into the Azov, Marmara, and Mediterranean Seas. In the Azov and Black Seas, massive outbreaks of the planktivorous *M. leidyi*, estimated at hundreds of million of metric tons, were linked to a 90% reduction in zooplankton biomass and significant decreases in commercial catches of anchovy and sprat (1989–1991). It was postulated that the population explosion of *M. leidyi* was in response to abundant zooplankton due to overfishing and eutrophication. By the late 1990s, the population of *M. leidyi* had declined and planktivorous fish species were reestablished. In November 1999, *M. leidyi* was recorded from the Caspian Sea. The following summer a massive outbreak (up to 170 individuals m^{-2}) occurred, from the saline south to the freshwater north, including the Volga delta. The immediate impact of the outbreak was a drastic reduction in the biomass and abundance of zooplankton, and deterioration in the size/weight ratio of the planktivorous anchovy-like kilka that form the bulk of the Caspian fisheries. The kilka catch in the first half of 2001 was but half that of the previous year. The endemic Caspian seal (*Phoca caspica*) is gravely endangered, as it feeds mainly on kilka.

Control: The Group of Experts on the Scientific Aspects of Marine Environment Protection (GESAMP) convened to discuss strategies for the control of *M. leidyi* and agreed that its eradication is unlikely, since the area affected was too large. Therefore, strategies were sought for reducing the species abundance. Mechanical removal or destruction was deemed impractical because of the high growth rate of the *Mnemiopsis* populations. Toxic nonspecific chemicals in the concentrations required to exterminate *Mnemiopsis* would damage the whole food web, and developing a *Mnemiopsis*-specific toxin requires large expenditures and a long time. Genetic control strategy was rejected since *Mnemiopsis* is a self-fertilizing simultaneous hermaphrodite so that spread of genetically altered genes would be unpredictable, in addition to the large investment in time and money needed. It was agreed that biological control using pathogens, parasites, predators, or competitors offers the only feasible approach. However, no diseases specific to ctenophorans have been identified. Parasitic trematode flatworms are found in ctenophores and may reduce their populations. However, as many trematodes also parasitize fish, their introduction as a biological control agent could cause damage to the fisheries. Infestation with the larvae of the burrowing sea anemone (*Edwardsia lineata*) affects the nutrition and growth of the ctenophore *M. leidyi* , however the larvae may also infest native species and the impacts of the adult anemone on the benthic community are unknown. The Group of Experts concluded that enhancement of native fish populations and ecological control by species introduction are the only feasible approach, given the constraints of limited time and financial resources. Three strategies were proposed: (a) rehabilitation of native pelagic fish stocks; (b) introduction of economically valuable fish that feed on or outcompete *M. leidyi*; and (c) introduction of a specific predator. It was recommended that the countries bordering on the Black Sea would cooperate to decrease fishing efforts and pollution to improve the native horse mackerel (*Trachurus mediterraneaus*) stocks. Three fish species, all feeding on gelatinous zooplankton, were considered as candidates for introduction: Baltic cod (*Gadus morhua callarias*), chum salmon (*Oncorhynchus keta*), and butterfish (*Peprilus triacanthus*). However, cod lives in colder waters and will be unable to feed on *M. leidyi* residing in summer in the warmer surface layer, the chum salmon may compete with native salmonids, and the reproductive biology of the butterfish is poorly known. Species of the ctenophore genus *Beroe* endemic to the Atlantic coast of America were considered as biocontrol agents as it feeds exclusively on gelatinous zooplankton and its reproductive rate and fecundity are as high as that of *M. leidyi*. *Beroe ovata* was recorded from the Black Sea in 1997. The rapid increase in its abundance was concomitant with significant reduction in *M. leidyi* biomass and increase in zooplankton and fish egg biomass. It has been suggested that *B. ovata* be introduced to the Caspian Sea.

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Biographical Sketch

Dr Bella Galil is Senior Scientist in the Israel Oceanographic and Limnological Research in Haifa, Israel, Associate Curator of Crustacea in the Zoological Museum of Tel-Aviv University. She got her PhD in Marine Biology at the Tel-Aviv University in 1983, defending the thesis entitled "Systematics, morphometric variation and genetic variation in *Trapezia* (decapoda, Xanthidae)". She is member of the CIESM task force for the atlas of exotic decapods in the Mediterranean Sea, and part of the editorial board of *Tropical Zoology* and *Biological Invasions*. She is author of 100 articles in reviewed journals dealing with decapod taxonomy, biology, and ecology, anthropogenic changes in the Mediterranean benthos, and biological invasions.