Marine Invasive Species in North America: Impacts, Pathways and Management

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INTRODUCTION

Species invasions into marine habitats, including range expansions and propagation in non-native ecosystems, occur naturally and as a result of human activities and are documented for five continents.[1] The introduction of invasive species is considered a major threat to marine and coastal environments as the rapid reproduction and competitive advantage of invasives allows them to dominate local ecosystems to the detriment of native species, thereby resulting in environmental alterations, human health impacts and economic losses worldwide.[2] Preventative measures, along with

* Our sincere thanks to two anonymous reviewers for providing insightful comments that have greatly improved this article.

1. N. Bax, A. Williamson, M. Aguero, E. Gonzales, and W. Geeves, ''Marine Invasive Alien Species: A Threat to Global Biodiversity,'' *Marine Policy* 27, 4 (2003): 313–323.

2. M. L. Reaka-Kudla, D. E. Wilson and E. D. Wilson, eds., *Biodiversity II: Understanding and Protecting our Biological Resources* (Washington: Joseph Henry Press, 1997); C. A. De Fontaubert, D. R. Downes and T. S. Agardy, *Biodiversity in the Seas: Implementing the Convention on Biological Diversity in Marine and Coastal Habitats*

Ocean Yearbook 20: 435–469.

management and control methods, have been developed using science and technology[3] where efficacy should be balanced against potential impact on native species and damage to local ecosystems.[4]

Contemporary international attention is primarily focused on the shipping industry due to the economic importance and extent of world shipping and the number of species that can be and are being transported via ballast water, tank sediments and hull fouling. Marine invasive species are also transported along other vectors, including aquaculture, canals, aquarium trade, recreational boating, hydrocarbon exploration and transportation activities and floating debris.[5] In general, these latter vectors receive less attention than shipping with the consequence that their contribution to the invasive species problem is not as well-known or recognized. Regulations and management initiatives reflect this claim, i.e., the development of marine transport treatment technologies, standards and evaluation and risk assessment procedures to control invasives is greatly advanced relative to that for the less prevalent vectors.[6]

A recent draft framework released in Canada, *Addressing the Threat of Invasive Alien Species: A Strategy for Canada*,[7] claims to seek the incorporation of principles related to a coordinated effort, setting priorities, assessing risk, and including environmental, social and economic considerations. The draft framework, while striving for breadth and inclusiveness, outlines the need for scientific information in shaping management decisions while the

(Cambridge: IUCN, 1996); D. Beach, *Coastal Sprawl: The Effects of Urban Design on Aquatic Ecosystems in the United States* (Arlington: Pew Oceans Commission, 2002); Global Ballast Water Management, 2000, ''The Problem,'' available online: <http://globallast.imo.org/index.asp?page=problem.htm>.

3. National Invasive Species Council (NISC), 2001. Management Plan, Meeting the Invasive Species Challenge, available online: <http://www.invasivespecies.gov/council/nmp.shtml>.

4. M. B. Thomas and A. J. Willis, ''Biocontrol—Risky But Necessary?,'' *Trends in Ecology and Evolution* 13, 8 (1998): 325–329; K. D. Lafferty and A. M. Kuris, ''Biological Control of Marine Pests,'' *Ecology* 77, 7 (1996): 1989–2000.

5. J. T. Carlton, ''Dispersal of Living Organisms into Aquatic Ecosystems as Mediated by Aquaculture and Fishing Activities,'' in A. Rosenfield and R. Mann eds., *Dispersal of Living Organisms into Aquatic Ecosystems* (Maryland Sea Grant College, University of Maryland, College Park, 1992): 13–46; D. Reid and M. Orlova, ''Geological and Evolutionary Underpinnings for the Success of Ponto-Caspian Species Invasions in the Baltic Sea and North American Great Lakes,'' *Canadian Journal of Fisheries and Aquatic Sciences* 59 (2002): 1144–1158; D. K. A. Barnes, ''Invasions by Marine Life on Plastic Debris,'' *Nature* 416 (2002): 808–809; J. T. Carlton, *Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities* (Arlington: Pew Oceans Commission, 2001).

6. Barnes, n. 5 above, at 808–809.

7. Environment Canada, Biodiversity Convention Office, 2004. Draft: *Addressing the Threat of Invasive Alien Species: A Strategy for Canada*. Available online: <http://www.bco.ec.gc.ca/en/activities/addressing.cfm>.

underlying data and evidence, particularly for marine invasive species, remains demonstrably inadequate. For example, while known invasive vascular plants, birds, insects, mammals, reptiles, amphibians, and freshwater fish are enumerated within the draft, marine invasives appear only in reference to ''several molluscs'' and with no distinction drawn between marine and freshwater species. Likewise, a discussion of economic threats includes detailed examples from the forestry and agriculture sectors, but warrants only two sentences addressing marine threats: the European green crab (*Carcinas maenas*) and the alga *Codium fragile*.

Knowledge of land-based species invasions and their potential impacts is typically more advanced than marine-based knowledge, perhaps in part because of the relative ease of studying land-based activities. This article, compiled prior to the release of *Addressing the Threat of Invasive Alien Species,*[8] concentrates on examples from the marine environment with an emphasis on Canada and the United States, except where examples from elsewhere provide additional comparative insights.

For the scope of this article, we define ''exotic'' species as those found outside of their normal range and ''invasive'' species as those that establish themselves and have a measurable impact once established. We define ''established'' species as organisms that are consistently reported to occur outside of their normal range, consequently they are considered to be noteworthy. We assume that once established, ''invasive'' organisms have an actual or potential effect (positive or negative) on any or all of native organisms, habitats, and encompassing environments.

We describe the potential ecological impacts of invasives and include a discussion of the importance of shipping as a force in the world's economy and as a pathway for invasives. In recognition of the disparate effort that has been directed at shipping in general, we also illustrate the diversity of vectors and potential risks associated with poorly monitored pathways. A discussion of the economic impacts of invasive species follows, illustrating that while some general information exists on the cost of aquatic invasions, those estimates are usually limited to direct damage or control expense and do not include indirect effects such as loss of biodiversity or compromised ecosystem services.[9] In spite of the limitations, managers are expected to make decisions regarding the control of invasives. Thus, we highlight some of the international and national policy tools that provide guidance to decision makers. Management actions for assessment and control of pathways and invasives are described and we address risk assessment

8. *Id.*

9. D. Pimentel, R. Zuniga and D. Morrison, ''Update on the environmental and economic costs associated with alien-invader species in the United States,'' *Ecological Economics* 52 (2005): 273–288.

methodologies that help set priorities. Contemporary initiatives for international collaboration and regional partnerships are explored and in the end we submit that the effective employment of the various tools and methods reviewed can provide the support necessary for managers to make informed decisions in addressing aquatic invasive concerns without full scientific certainty.

ECOLOGICAL CONCERNS

A growing number of exotic aquatic species are being introduced via an increasingly diverse group of vectors that have emerged out of increasingly complex transportation systems and widespread human activities.[10] For example, the rate of species introduction in the United States' coastal zone has grown exponentially since the 18th century (Figure 1),[11] with San Francisco Bay as a prime example. Invasion rates in this area have increased from an average of one species every nine months during the period from 1850 to 1970, to one species every six months since 1970 (Figure 2).[12]

One estimate suggests that 85 percent of all exotic plants and animals do not pose a problem to native species.[13] The remainder, however, may threaten existing ecosystems with varying magnitude and severity, depending on the species involved and the complexity of the affected ecosystem.[14] Manifest impacts of marine invasive species include rapid reproduction rates that give rise to large dominant populations, local native extinctions due to population outbreaks, alteration of physical environments, transfer of pathogens and modifications to food webs.[15] For example, many planktonic species have long-lived reproductive stages (spores, cysts or eggs) that remain viable in unfavourable conditions.[16] Toxic dinoflagellates, along

10. Bax et al., n. 1 above, at 313–323; Union of Concerned Scientists, *The Science of Invasive Species* (California, 2001) 12 pp.; Carlton, 1992, n. 5 above, at 13–46.

11. Carlton, 2001, n. 5 above.

12. A. N. Cohen and J. T. Carlton, ''Accelerating Invasion Rate in a Highly Invaded Estuary,'' *Science* 279 (1998): 555–558.

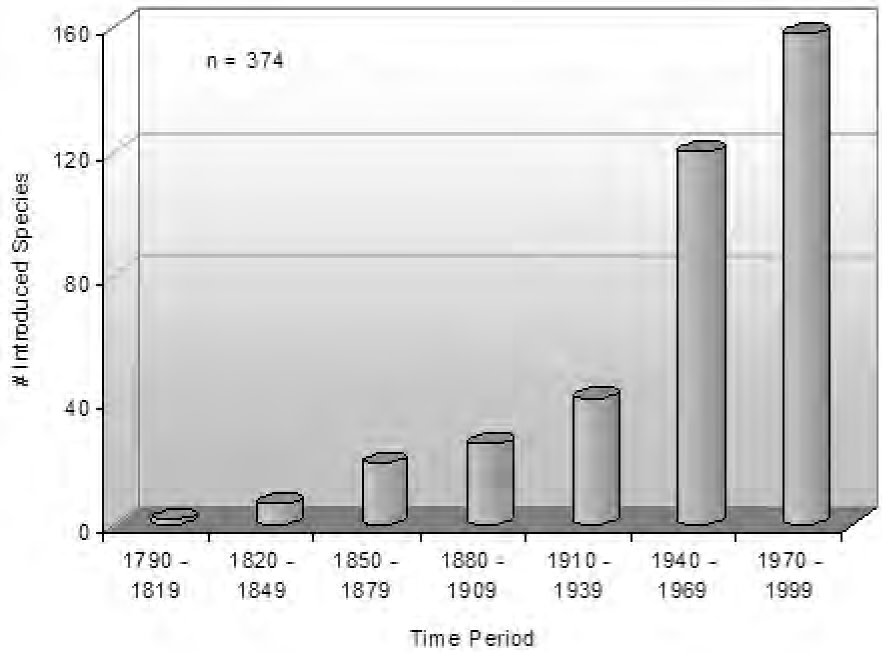
13. N. Kassulke, ''Tales from the Exotics Battlefront,'' *Wisconsin Natural Resources Magazine*, 2001, available online: <http:// www.wnrmag.com/supps/2001/jun01>.

14. IMO (International Maritime Organization), *International Convention for the Control and Management of Ships Ballast Water and Sediments,* adopted 13 February 2004; J. T. Carlton, ''Patterns of Transoceanic Marine Biological Invasions in the Pacific Ocean,'' *Bulletin of Marine Science* 41, 2 (1987): 452–465.

15. *Id.*

16. J. P. Hamer, T. A. McCollin and I. N. Lucas, ''Dinoflagellate Cysts in Ballast Tank Sediments: Between Tank Variability,'' *Marine Pollution Bulletin* 40 (2000): 731–733.

FIG. 1.—Number of Introduced Species in U.S. Marine Waters from 1790 to 1999 at 30-Year Intervals. The Recent 60 Years Represent ~70 Percent of the Total.



Source: Carlton; n. 5 above.

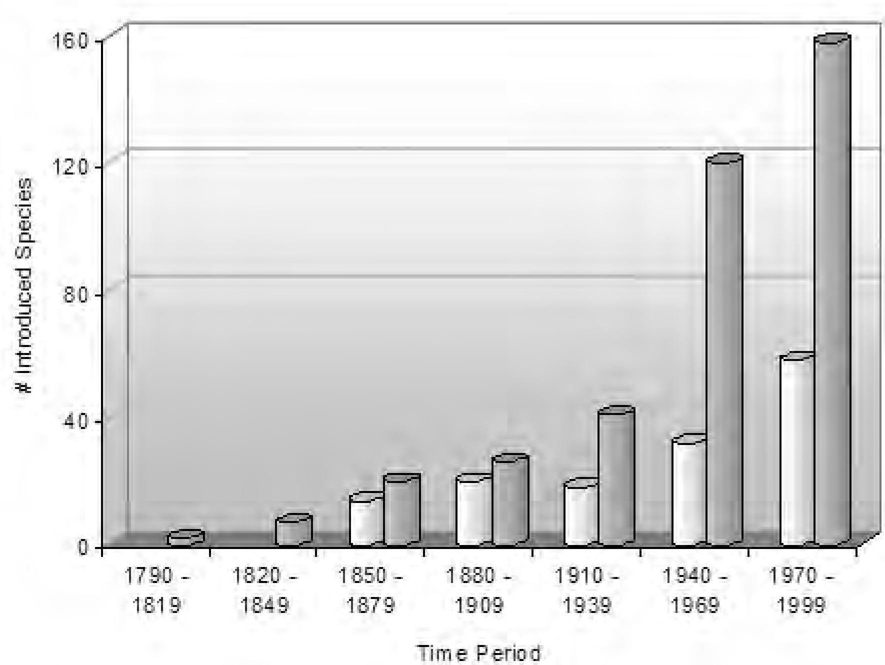
with other algal species, can cause the death of fish or shellfish and pose a serious risk to human health.[17] Rapidly expanding invasive populations can deplete oxygen, thereby resulting in fish deaths, altered habitats and community assemblages, fouled stabilizing structures and water intakes and reduced primary productivity so essential for marine food chains.[18] As all ecosystems appear to show some vulnerability to invasive species, and as the consequences of a successful invasion are often irreversible,[19] greater awareness by policy makers is essential if they are to devise appropriate

17. G. M. Hallegraeff and C. J. Bolch, ''Transport of Toxic Dinoflagellate Cysts Via Ships Ballast Water,'' *Marine Pollution Bulletin*, 22 (1991): 27–30.

18. E. Grosholz, ''Ecological and Evolutionary Consequences of Coastal Invasions,'' *Trends in Ecology and Evolution* 17, 1 (2002): 22–27; J. Cloren, ''Phytoplankton Bloom Dynamics in Coastal Ecosystems: A Review with Some General Lessons from Sustained Investigations of San Francisco Bay, California,'' *Review of Geophysics* 34 (1996): 127–168.

19. M. Doelle, ''The Quiet Invasion: Legal and Policy Responses to Aquatic Invasive Species in North America,'' *International Journal of Marine Coastal Law* 18, 2 (2003): 261–294.

FIG. 2.—San Francisco Bay has long been a known recipient of invasive species in United States. From 1850 to 1909 the number of new introductions in San Francisco Bay represented more than 50 percent of the total known species introductions in U.S. Since 1910 San Francisco Bay has been responsible for approximately 30 percent of the total species introduced.



Sources: Carlton, n. above; A. N. Cohen and J. T. Carlton, Nonindigenous Aquatic Species in a United States Estuary: A Case Study of the Biological Invasions of the San Francisco Bay and Delta (Berkeley: University of California, Williams College—Mystic Seaport, 1995)

responses for possible impacts. The necessity of a coordinated and focussed management response becomes readily apparent with increasing awareness of the many and diverse ways that species may be introduced.[20] In general, contemporary and historical regulations have proven ineffective in mitigating the harmful effects of invasions.[21]

20. Carlton 1992, n. 5 above, at 13–46.

21. O. Endresen, H. L. Behrens, S. Brynestad, A. B. Andersen and R. Skjong, ‘‘Challenges in Global Ballast Water Management,’’ *Marine Pollution Bulletin* 48 (2004): 615–623; Bax et al., n. 1 above, at 313–323; Doelle, n. 19 above, at 261–294.

Marine Transport

Marine transportation has long been suspect as an important vector of species transfer,[22] though ballast-tank inspections did not confirm its role until the 1970s. Attempts to prevent ballast water dispersal of invasive species have been underway since the early 1990s.[23] Ballast water, tank sediments and hull fouling are now widely accepted as important vectors for the introduction of exotic marine species around the world.[24]

Accounting for 80 percent of world trade, shipping is the dominant mode of transport accounting for 10,429 million tonnes (M mt) of cargo transported each year.[25] The transport of cargo by shipping is facilitated by the corresponding transfer of 3500 M mt of ballast water used to maintain vessel balance, stability and structural integrity (Table 1).[26] Ballast water can contain unwanted marine organisms that can be carried around the world and discharged into new environments.[27] Contemporary estimates provide for 2,800 M mt of ballast water discharged annually worldwide,[28] and while most species die without becoming established, some species do survive to form viable populations. The development of steel-hulled vessels, increased ballast volume and reduced trip duration increase the probability of successful establishment by exotic species.[29] While ballast water has received

22. C. J. Ostenfeld, ''On the Immigration of Biddulphia Sinesis Grev. and Its Occurrence in the North Sea During 1903–1907,'' *Medd. Komm. Havunders., Ser. Plankton* 1 (1908): 44 pp., as cited in Hallegraeff et al., n. 17 above.

23. R. J. Williams, F. B. Griffiths, E. J. Van der Wal and J. Kelly, ''Cargo Vessel Ballast Water as a Vector for the Transport of Non-Indigenous Marine Species,'' *Estuarine, Coastal and Shelf Science* 26 (1988): 409–420; GloBallast (Global Water Management Programme), 2003a, Ballast Water Treatment R&D Directory, International Maritime Organization, 75 pp.

24. J. T. Carlton and T. B. Geller, ''Ecological roulette: The Global Transport of Nonindigenous Marine Organisms,'' *Science* 261 (1993): 78–82; P. N. Lewis, C. L. Hewitt, M. Riddle and A. McMinn, ''Marine Introductions in the Southern Ocean: An Unrecognized Hazard to Biodiversity,'' *Marine Pollution Bulletin* 46 (2003): 213–223; Endresen et al., n. 21 above, at 615–623.

25. UNCTAD (United Nations Conference on Trade and Development), 2003, *Review of Maritime Transport, 2003: Report by the UNCTAD Secretariat* (Geneva: United Nations Conference on Trade and Development, UN 387.5 P3), 140 pp.; J. Hoffmann and S. Kumar, ''Globalization: The Maritime Nexus,'' In: C. Grammenos, ed., *Handbook of Maritime Economics and Business* (London: London Press, 2002): 35–62.

26. D. Pughuic, ''Ballast Water Management and Control: An Overview,'' *Tropical Coasts*, 7 (2001): 42–49; Endresen et al., n. 21 above, at 615–623; Hoffman et al., n. 25 above, at 35–62.

27. Endresen et al., n. 21 above, at 615–623.

28. *Id.*

29. J. G. Field, G. Hempel and C. P. Summerhayes, *Oceans 2020: Science, Trends, and the Challenge of Sustainability* (Washington: Island Press, 2002), 177 pp.

the majority of attention directed at ship-mediated biological invasions, ''no ballast on board'' (NOBOB) vessels do in fact contain some ballast and tank sediment though they are effectively unregulated.[30] Once released, invasives can disrupt the natural ecological balance of the receiving ecosystem by out-competing native species for resources and upsetting predator-prey relationships.[31]

Table 1.—World Ship Cargo Trade (mt) among Regions in 2000

Region	*Exports*	*Imports*	*Total*
Asia Pacific	1,395	2,106.1	3,501.1
Europe	673.4	1,421.8	2,095.2
North America	536.2	910.7	1,446.9
Latin America / Caribbean	948.3	313	1,261.3
Persian Gulf	832.3	76.2	908.5
Other	829.2	386.6	1215.8
Total	5,214.5	5,214.5	

Source: Hoffmann et al., n. 25 above.

In addition to ballast water and tank sediment, hull fouling is a mechanism for species conveyance worldwide. The impact of methods used to reduce hull fouling offers a note of caution for potential management. Effective antifouling hull coatings (e.g., containing tributyl tin, TBT) offer some environmental benefits that include decreased fuel consumption, reduced fuel combustion emission and the reduction of invasive species via hull fouling. However, the environmental cost associated with such treatments can be considerable,[32] a subject further addressed below. As the size and number of vessels in the world shipping fleet continues to grow,[33] the problems associated with marine transportation will escalate in parallel, with possible intensification resulting from increasing coastal eutrophica-

30. L. A. Drake, P. T. Jenkins and F. C. Dobbs, ''Domestic and International Arrivals of NOBOB (No Ballast on Board) Vessels to Lower Chesapeake Bay,'' *Marine Pollution Bulletin* 50 (2005): 560–565.
31. GloBallast 2003a, n. 23 above.
32. S. M. Evans, A. C. Birchenough and M. S. Brancato, ''The TBT Ban: Out of the Frying Pan into the Fire?,'' *Marine Pollution Bulletin* 40, 3 (2000): 204–211; A. O. Valkirs, P. F. Seligman, E. Haslbeck and J. Caso, ''Measurement of Copper Release Rates from Antifouling Paint Under Laboratory and In Situ Conditions: Implications for Loading Estimation to Marine Water Bodies,'' *Marine Pollution Bulletin* 46 (2003): 763–779.
33. UNCTAD, n. 25 above.

tion.[34] Shipping is clearly important to world trade and simultaneously to the spread of invasive species. Consequently, shipping receives an inordinate amount of attention directed to regulatory activities and control mechanisms,[35] often overshadowing the considerable risks posed by many other transport vectors.

Other Vectors

Vectors recognized for their potential to spread exotic species include aquaculture, canal development, aquarium trade, floating marine debris, and oil and gas development activities. The magnitude and extent of invasive impact from vectors other than shipping have been described on occasion, but much work remains before sufficient information will be available for reliable decision making purposes. As much as 60 percent of marine invasive plants can be transferred by means distinct from shipping (Table 2).[36] Illustrating this point, 56 exotic species have been identified in an estuary receiving no international shipping.[37] Bax et al. suggest that mariculture could be responsible for up to 25 percent of exotic species establishments,[38] through deliberate and/or accidental releases of target organisms, along with their ''hitchhiking'' pathogens or parasites.[39] In a similar vein, intentional or accidental releases of aquarium species into coastal ecosystems have the potential to create ecosystem instability. A well-known example is that of *Caulerpa taxifolia*, an alga native to the tropics that was accidentally released in 1984 from the Oceanographic Museum of Monaco. It has flourished and contemporary estimates have it covering 30,000 hectares of coastal sea floor adjacent to six Mediterranean countries. The same alga was discovered in Agua Hedionda Lagoon in California,[40]

34. F. Zhang and M. Dickman, ''Mid-Ocean Exchange of Container Vessel Ballast Water. 1: Seasonal Factors Affecting the Transport of Harmful Diatoms and Dinoflagellates,'' *Marine Ecology Progress Series* 176 (1999): 243–251.

35. A. Ricciardi, ''Facilitative Interactions among Aquatic Invaders: Is an 'Invasional Meltdown' Occurring in the Great Lakes?,'' *Canadian Journal of Fisheries and Aquatic Sciences* 58 (2001): 2513–2525; Endresen et al., n. 21 above, at 615–623.

36. M. A. Ribera Siguan, ''Review of Non-Native Marine Plants in the Mediterranean Sea,'' in E. Leppakoski, S. Gollasch and S. Olenin, eds., *Invasive Aquatic Species of Europe-Distribution Impacts and Management* (London: Kluwer Academic Publishers, 2002), 291–310.

37. K. Wasson, C. J. Zaban, L. Bedinger, M. C. Diaz and J. S. Pearce, ''Biological Invasions of Estuaries Without International Shipping: The Importance of Intraregional Transport,'' *Biological Conservation* 102 (2001): 143–153.

38. Bax et al., n. 1 above, at 313–323.

39. Carlton, n. 5 above, at 513–546.

40. C. Wabnitz, M. Taylor, E. Green and T. Razak, *From Ocean to Aquarium* (Cambridge: UNEP-World Conservation Monitoring Centre, 2003).

where chlorine was used in an eradication attempt at a cost of US$1.5 million.[41]

Table 2.—Relative Magnitude of Vectors Responsible for Transfer of Exotic Marine Plants

Vector	*No. of Exotics*	*Percent*
Shellfish Transport	49	30
Ship Fouling	39	24
Ballast	25	16
Suez Canal	24	15
Import for Aquaculture	15	9
Other Vectors (Research, Fishing, Aquaria)	10	6

Source: Ribera Siguan, n. 36 above.

The construction of canals to improve shipping removes natural barriers and facilitates the active or passive dispersal of invasive species such as zebra mussels (*Dreissena polymorpha*), cladocerans and jellyfish across broad biogeographic regions.[42] Such species have profoundly modified ecosystems ranging from the Black Sea to the Great Lakes and have severely reduced or altered important commercial fish catches in such regions.[43]

Commercial fishing provides a transport vector for invasives through fouling of boat wells, hulls and equipment,[44] while transient boaters are suspect as a major vector for overland dispersal.[45] There is evidence that

41. J. Withgott, ''California tries to rub out the monster of the lagoon,'' *Science* 295 (2002): 2201–2202.

42. Reid et al., ''Geological and Evolutionary Underpinnings for the Success of Ponto-Caspian Species Invasions in the Baltic Sea and North American Great Lakes,'' *Canadian Journal of Fisheries and Aquatic Sciences* 59 (2002): 1144–1158; E. Leppakoski, S. Gollasch, P. Gruszka, H. Ojaveer, S. Olenin and V. Panov, ''The Baltic-A Sea of Invaders,'' *Canadian Journal of Fisheries and Aquatic Sciences* 59 (2002): 1175–1188; S. Gollasch, D. Minchin, H. Rosenthal and M. Voigt, eds., *Exotics across the Ocean: Case Histories on Introduced Species* (Kiel: Department of Fishery Biology, Institute of Marine Science, University of Kiel, 1999).

43. A. Ricciardi, n. 34 above, at 2513–2525; Reid et al., n. 42 above, at 1144–1158.

44. Anonymous, *Marine Pest Information Sheet: Vessel and Gear Fouling,* Centre for Research on Marine Invasive Pests, 2004, available online: <http://crimp.marine.csiro.au>.

45. D. K. Padilla and L. E. Johnson, ''Geographic Spread of Exotic Species: Ecological Lessons and Opportunities from the Invasion of the Zebra Mussel,'' *Biological Conservation* 78 (1996): 23–33.

invasion rates in enclosed marinas can be 3- to 19-fold greater than in adjacent coastal areas.[46] In 2000, inspections conducted in Maine (U.S.) showed that 4 percent of recreational boats carried water milfoil (exotic freshwater vascular plant) at a time when an outbreak was occurring in the State.[47] The estimated 50,000 boats that cross the State borders each year represent considerable potential for the import and export of invasive species.

Floating marine debris (FMD) poses two significant environmental threats. First, as foreign and polluting objects, and second, through passive wind and current transport it can carry invasive hitchhikers over long distances.[48] Before Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL) came into force in 1988 it was estimated that the shipping industry discarded 639,000 plastic containers into the marine environment each day—over 233 billion containers annually.[49] One study in the South Pacific, subsequent to the adoption of Annex V, revealed a significant increase in marine littering coincident with a decrease in publications on the activity and suggested that Annex V might not have been as responsible for reducing marine litter as previously assumed by the scientific community.[50] Studies have shown bryozoans and barnacles to have crossed the Tasman and Caribbean Seas and the North Atlantic Ocean while attached to FMD.[51] Generally, invasions facilitated by FMD occur in mid-latitudes (<60°), possibly excluded from the higher latitudes by rough seas, cold temperature and increased intensity of ultraviolet light.[52] The potential effects of global warming on the future transport and survival of organisms to higher latitudes are virtually unknown.[53]

Oil and gas maintenance and replacement activities also act as invasive vectors. In 1991, the corals *Tubastraea coccinea* and *Mycetophyllia rees* were identified growing on 11 oil platforms off the coasts of Texas and Louisi-

46. National Institute of Water and Atmospheric Research, ''Biosecurity and Human Health: What's on the Bottom of Your Boat?'' *Biodiversity Update* 2 (2001): 1.
47. Land and Water Resources Council, ''Action Plan for Managing Invasive Aquatic Species,'' Maine, 2002, available online: <http://www.state.me.us/>.
48. Barnesk, n. 5 above, at 808–809.
49. International Legal Materials, 12 (1973): 1319; International Convention for the Prevention of Pollution from Ships, (MARPOL), UN Legislative Series ST/LEG/SER.B/18 of 2 November, 1973, (1973) 12 *International Legal Materials* 1319; J. G. B. Derraik, 2002, ''The Pollution of the Marine Environment by Plastic Debris: A Review,'' *Marine Pollution Bulletin* 44 (2002): 842–852.
50. P. G. Ryan and C. L. Moloney, ''Biodiversity Invasions by Marine Life on Plastic Debris,'' *Nature* 416 (April 25, 2002): 808–809.
51. Derraik, n. 49 above, at 842–852.
52. *Id.*
53. Barnes, n. 5 above, at 808–809.

ana.[54] Prior to that discovery, they had only been observed in the Gulf of Mexico on oil platforms off the coasts of Campeche and Veracruz. The logical connection is that they appeared off Texas and Louisiana through the movement of oil rigs.[55]

ECONOMIC ASPECTS

Biodiversity protection is difficult to incorporate in policy, and little incentive exists for vector-control initiatives unless there are obvious and measurable impacts to human health or the economy.[56] Despite the availability of data on ecological impacts of invasive species and the methods of their transport, few efforts to quantify realized costs and benefits associated with an invasion have reached specific and complete assessment. Difficulties remain in communicating the economic risks associated with invasive species, as contemporary economic models may be inadequate to gauge indirect effects.

Effects resulting from the presence of invasive species are difficult to separate from those caused by climate change and other forms of habitat alteration and pollution, and assessing attributes like aesthetic value or human well-being presents an even greater challenge. There are no ''standard methods'' to collect and/or analyse invasive-related economic data and no central databases or collaborative bodies of knowledge to illustrate the consequences of past decisions or to inform future decisions. The inter-connected nature of the marine environment makes it difficult to attach costs to specific sectors—some invasives have the potential to damage many industries simultaneously, but only a broad overall cost is determined. A damage estimate exceeding $1 billion resulting from invasions into the United States of the European green crab (*Carcinus maenus*), the Asian clam (*Corbicula fluminea*) and the shipworm (*Teredo navalis*) is expected to range across several industries, including aquaculture, fisheries, marine infrastructure and shipping.[57] Beyond such specific examples, precise economic costs for marine invasive species are not readily available. If estimates have been attempted they often include only damage or control costs; indirect costs such as biodiversity loss, aesthetic impacts or degraded ecosystem services are seldom, if ever, approximated.[58] In general, control or eradication of

54. D. Fenner, ''Biogeography of Three Caribbean Corals (Scleractinia) and the Invasion of Tubastraea Coccinea into the Gulf of Mexico,'' *Bulletin of Marine Science* 69, 3 (2001): 1175–1189.
55. *Id.*
56. Doelle, n. 19 above, at 261–294.
57. Pimentel et al., n. 9 above, at 273–288.
58. *Id.*

invasive species is expensive and an accurate assessment of costs with the goal of determining how best to spend mitigative effort is difficult.

The world economy is heavily dependent on maritime shipping and shipping is a major vector for invasive species. To curtail invasives, new treatment methods are necessary that will require equipment installations, especially on older vessels. Onboard ballast water treatment systems and deep water ballast exchange are two methods that result in increased operating costs. The International Maritime Organization (IMO) has suggested that ballast water exchange could add US$160 million to annual shipping costs and in some cases could increase the potential for capsizing.[59] The IMO currently sponsors ballast water management research programs, each costing nearly $70,000,[60] and has partnered with the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP) to assist developing countries to implement IMO ballast water guidelines through Globallast—the Global Water Management Program. Globallast demonstration sites are established in six countries at a cost of US$10.2 million.[61] As fouling from ballast water does not create a direct negative economic impact for the shipping industry, the costs associated with improvement of ballast exchange methods to prevent fouling may not seem to be a worthwile investment for the shipping industry. This is not the case with hull fouling. A fouled hull increases drag resulting in increased fuel consumption and cost. Thus, reduced hull fouling has the incentive of reduced cost.[62]

Marine invertebrates can damage coastal infrastructure or obstruct waterways. For example, the Asian clam and the shipworm can threaten native species, damage coastal piers and structures, block intake pipes, and destabilize banks.[63] Freshwater species such as the Asian clam and the zebra mussel (*Dreissena polymorpha*) are tolerant of estuarine conditions.[64] Damage

59. G. R. Rigby and G. M. Hallegraeff, ''The Transfer and Control of Harmful Marine Organisms in Shipping Ballast Water: Behaviour of Marine Plankton and Ballast Water Exchange on the MV 'Iron Whyalla,' '' *Journal of Marine Environmental Engineering* 1 (1994): 91–110.

60. D. Oemeke, ''Ballast Water Treatment Technology,'' *Port Corporation of Queensland Research and Development on Ballast Water Technology*, 1998 as cited in IMO-Globallast, 2004, n. 14 above.

61. IMO (International Maritime Organization), 2004, n. 14 above; Global Water Management Program website: <http://globallast.imo.org/index.asp?page=gef_interw_project.htm&menu=true>.

62. Evans et al., n. 32 above, at 204–211; Valkirs et al., n. 32 above, at 763–779; Lewis et al., n. 24 above, at 213–223; Bax et al., n. 1 above.

63. Pimentel et al., 2005, n. 9 above, at 273–288; D. Pimentel, ed., *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species* (Boca Raton: CRC Press, 2002), 369 p.

64. P. W. Fofonoff and G. M. Ruiz, ''Biological Invasions in the Cheasapeake and Delaware Bays: Patterns and Impacts,'' *Proceedings of the Aquatic Invaders of the*

from the zebra mussel has received much more comprehensive documentation than many other marine invasive species and consequently it can be used as a surrogate in attempts to predict potential impacts arising from similar marine invertebrates. Annual North American expenditures for the control of the zebra mussel increased 70 fold from $234,140 in 1989 to $17,751,000 in 1995, perhaps a glimpse of the potential economic impact associated with the invasive saltwater mussel *Perna viridis*.[65] Impacts can encompass damage to infrastructure, reductions in tourism, altered recreational activities, algal clogging of waterways and threats to human health.[66] The impacts of some are easily quantified while others, such as the loss of human life are more appropriately moral or ethical issues.[67]

Aquaculture practices introduce a unique set of concerns. The propagation of native and non-native species can be equally problematic, however, we preferentially address the latter, recognizing that the control of invasive species within aquaculture may not be a complete solution. From an aquaculture perspective, the non-native (otherwise invasive) species are of economic benefit—in fact a necessity. Nearly 10 percent of the 22 M mt of worldwide aquaculture production (marine and freshwater) is founded on the culture of non-native species (Figure 3).[68] Regionally, up to 50 percent of aquaculture production is derived from non-native species.[69] For example, 90 percent of global seaweed production occurs in China,[70] where the introduced kelp *Laminaria japonica* is responsible for about 50 percent of total production.[71] The commercial cultivation of non-native species poses serious threats to the local ecosystem and its native species, e.g., the release of parasites and disease from cultured organisms to the environment.[72] On occasion, the economic benefits of aquaculture using non-indigenous species have been balanced by the reporting of negative economic impacts, such as an outbreak of *Haplosporidium nelsoni* MSX

Delaware Estuary Symposium, Malvern, Pennsylvania, May 20, 2003. 5–8, available online: <http://www.signis.org/publicat/proceed/aide/foforuiz.htm>.

65. C. R. O'Neill, Jr., ''Economic Impact of Zebra Mussels-Results of the 1995 National Zebra Mussel Information Clearinghouse Study,'' *Great Lakes Research Review* 3, 1 (April 1997): 33–44.

66. Bax et al., n. 1 above.

67. *Id.*

68. L. Garibaldi, ''List of Animal Species Used In Aquaculture,'' FAO Fisheries Circular No. 914 FIRI/C914 (Rome: FAO, 1996).

69. *Id.*

70. FAO, *The State of World Fisheries and Aqaculture 2002* (Rome: FAO FisheriesDepartment, 2002).

71. K. Lüning and S. Pang, ''Mass Cultivation of Seaweeds: Current Aspects and Approaches,'' *Journal of Applied Phycology* 15 (2003): 115–119.

72. N. L. Naylor, J. Eagle, and W. L. Smith, ''Salmon Aquaculture in the Pacific Northwest: A Global Industry with Local Impacts,'' *Environment* 45, 8 (2003): 18–39.

(Multinucleate Sphere X) disease in oyster populations that destroyed an estimated 75 percent of cage-cultured oysters at Cape Breton's (Canada) largest oyster producer in spring 2003, and spread to local ecosystems.[73] In other instances, the escape of cultured organisms has been reported, but the consequential economic impacts have not. Contemporary estimates suggest over one million Atlantic salmon (*Salmo salar*) have escaped from farms in British Columbia and Washington State since 1991 and the non-native species has subsequently been reported in the wild in at least 80 rivers ranging from British Columbia to the Bering Sea.[74] Escapes occur as a result of storms, human error and predatory attacks on aquaculture facilities by marine mammals. Escaped animals can transmit disease and parasites to wild stock, feed on native species, and compete with native species for habitat and food requirements.[75] In short, the culturing of non-indigenous species can provide strong economic benefit (subsidized or not) in concert with equally subsidized negative ecological impact; the benefit accrues to private interests while the costs become externalized (Figure 3).[76]

Invasive species can negatively impact the wild-harvest fishery through predation or competition with commercially exploited species,[77] damage to fish-protection devices on intakes,[78] damage to fishing gear,[79] and export barriers for fish products because of disease concerns.[80] However, there is a paucity of data accurately describing the economic consequences of damage caused by invasive species on wild fishery resources (Table 3).[81]

In Canada, damage from identified aquatic nuisance species has been estimated at $343 million annually, mostly to commercial and sport

73. A. MacIssac, pers. comm., 24 March 2004; Fofonoff et al., 2003, n. 64 above, at 5–8.

74. Atlantic Salmon Watch Program statistics, available online: <http://www.pac.dfo-mpo.gc.ca/sci/aqua/ASWP/Asl_escapes.pdf>; Naylor, et al., n. 72 above, at 18–39.

75. Naylor, et al., n. 72 above, at 18–39.

76. J. E. Bardach, "Aquaculture, Pollution and Biodiversity," in *Sustainable Aquaculture* ed., J. E. Bardach, (New York: John Wiley and Sons, Inc., 1997); C. Perrings, "Biological Invasions in Aquatic Systems: The Economic Problem," *Bulletin of Marine Science* 70, 2 (2002): 541–552.

77. R. Mann and J. M. Harding, "Invasion of the North American Atlantic coast by a large predatory Asian mollusc," *Biological Invasions* 2, 1 (2000): 7–22.

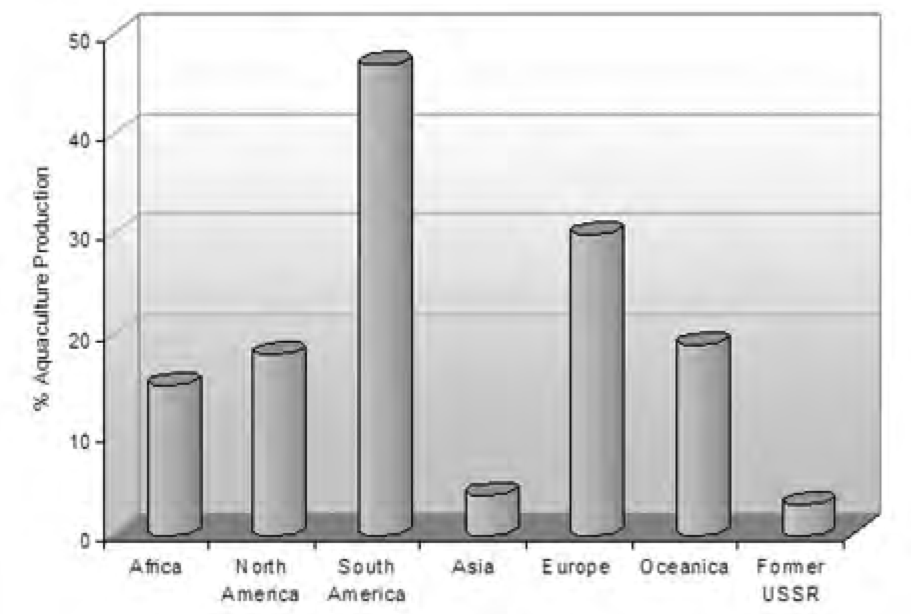
78. Lafferty et al., n. 4 above, at 1989–2000.

79. W. M. Graham, D. L. Martin, D. L. Felder, V. L. Asper and H. M. Perry, "Ecological and Economic Impacts of a Tropical Jellyfish Invader in the Gulf of Mexico," *Biological Invasions* 5, 1–2 (2003): 53–69.

80. R. Claudi, "Environmental and Economic Costs of Alien Invasive Species in Canada," *Report for the Canadian Information System for the Environment* (Ottawa: RNT Consulting, Inc. March 26, 2002).

81. *Id.*

FIG. 3.—Percentage of total aquaculture production of introduced species by country.



Source: Garibaldi, n. 68 above.

Table 3.—Contemporary Knowledge Base for Invasive Impacts on Canadian Economy and Environment

Species	*Number of References*	*References with Dollar Value*
Fourspine Stickleback *Apeltes quadracus*	2	0
Salmonid disease *Piscirickettsia salmonis*	2	0
Round goby *Neoglobus melanostormus*	11	0
Whirling disease *Myxobolus cerebalus*	20	0

Source: Claudi, n. 80 above.

fisheries.[82] The wide confidence interval ($298 to $776 million) around such an estimate illustrates the high degree of uncertainty, largely associated with sparse data, in determining the economic impacts of invasives. Attempts to quantify the economic impacts of nuisance species rarely extend to the marine environment (Table 4).[83] In North America, economic studies that address the impacts of invasive species are rare, often localized to a particular industry or area, and typically describe only direct cost or current worth associated with a threatened industry (Table 4). For example, the European green crab is an invasive species currently considered to threaten some of Canada's most lucrative shellfish fisheries on both coasts (Table 4). In the United States, attempts have been made to quantify direct damage by invasive species on specific fisheries or localities (Table 4), but indirect impacts (e.g., increases in predation by jellyfish on some fish) have not been quantified.[84] The difficulty involved in identifying marine invasions, let alone evaluating them, is a problem partially attributable to limited public awareness of the problem.[85] A global invasion tracking system may facilitate early response, help set priorities, supply information needed for management actions, and allow consideration of low-risk and beneficial introductions.[86]

MANAGEMENT ACTIONS

Following the establishment of an invasive species within a given ecosystem, the invader can exert a devastating influence and be very difficult and costly to eradicate or even control. Adequate legal authority and administrative support, paired with early assessment and control activities, significantly increases the potential to effectively reduce the impact of invasive species on natural systems.[87] Globally, at least 45 binding and non-binding internation-

82. R. I. Colautti, S. A. Bailey, C. D. A. van Overdijk, K. Amundsen and H. J. MacIssac, ''Characterised and Projected Costs of Nonindigenous Species in Canada,'' *Biological Invasions* (in press).

83. *Id.*

84. Graham et al., n. 79 above, at 53–69.

85. Bax et al., n. 1 above, at 313–323.

86. A. Ricciardi, W. Steiner, R. Mack and D. Simberloff, ''Toward a Global Information System for Invasive Species,'' *Bioscience* 50, 3 (2000): 239–244; B. Morton, ''The Nature of the Aquatic Nuisance Species Problem: A Global Perspective,'' In *Sixth International Zebra Mussel and Other Aquatic Nuisance Species Conference, Dearborn, Michigan, March 1996* Unpublished document; C. R. Townsend, ''Individual, Population, Community, and Ecosystem Consequences of a Fish Invader in New Zealand Streams,'' *Conservation Biology* 17, 1 (2003): 38–47.

87. J. A. McNeely, L. E. Neville and M. Rajmanek, ''When Is Eradication a Sound Investment?,'' *Conservation in Practice* 4, 1 (2003): 30–31.

Table 4.—Available Invasives-Related Economic Data from Canada and the United States

Invasive	*Sector*	*Impact*	*Cost*	*Reference*
European Green Crab	Fisheries	Predator of invertebrates and seaweeds. Threatens recreational and commercial shellfish fisheries.	Threat to fisheries: $200 million/yr shellfish, $25 million crab fishery. (BC and Washington) $57 million clam, mussel and oyster, $500 million lobster (Canadian Atlantic).	Standing Committee Report 2003
Chinese Mitten Crab	Fisheries	Fouls fish bypass structures on power plants: 51,000 crabs/day on fish bypass structures in 1999.	98–99 percent fish mortality at the Federal facility through the summer of 1999: over $1 million in losses.	Chinese Mitten Crab Task Force 2002
Jellyfish *Phyllorhiza punctata*	Fisheries	Clogs shrimp nets and preys on eggs and larvae of commercially important species. Gulf of Mexico, abund. in the summer of 2000 = $5.37 \times 10^6/150km^2$	Shrimp net damage estimated at millions of dollars. No attempt to quantify the damage to fish stocks caused by increased egg and juvenile mortality.	Graham et al. 2003

Sources: Standing Committee on Fisheries and Oceans, T. Wappel, Chair, *Aquatic Invasive Species: Uninvited Guests.* Fourth Report of the Standing Committee on Fisheries and Oceans (Ottawa: Communication Canada Publishing, Ottawa, 2003), 38 p.; Chinese Mitten Crab Task Force, *A Draft National Management Plan for the Genus Eriochheir*, Submitted to the Aquatic Nuisance Species Task Force, US, 2002, available online: <http://anstaskforce.gov/chinese-mitten-crab-plan2–02.pdf>; W. M. Graham, D. L. Martin, D. L. Felder, V. L. Asper and H. M. Perry, ''Ecological and Economic Impacts of a Tropical Jellyfish Invader in the Gulf of Mexico,'' *Biological Invasions* 5, 1–2 (2003): 53–69.

al conventions and agreements address aquatic invasive species—many that concentrate on marine invasions.[88] About half of these instruments have implications for aquatic invasive species in North America.[89]

A number of means exist to manage and control invasive species and they require a combination of scientific and management techniques for success to accrue. Risk assessment can be useful as a tool to assess proposed (or potential) introductions, but it represents only one of many devices and should not be the sole basis for decision-making.[90] Often, information needed to produce a rapid response is unavailable or unattainable, and controlling the invader becomes increasingly difficult if the response is delayed by the time required to secure the necessary information.[91] We offer a simple illustration. Much of the available literature addresses terrestrial problems and examples, however, the marine environment is very different from its terrestrial counterpart. Despite this, the precautionary approach is explicitly described in Canadian policy and legislation, and work is proceeding to standardize its implementation in science-based decision making across federal departments, suggesting a commitment to the principle. Conversely, the need for more research is not an excuse for inaction, especially with new invasions occurring at an exponential rate.[92] Thus, managers must be guided by clear, proactive policies, must employ risk assessment tools, and must secure useful and credible information and commit to institutional sharing of insights as a means of dealing with uncertainty.

Legal and Administrative Support

Contemporary concerns regarding invasive species are being addressed by governments, institutions, policy and planning interest groups and individuals. Internationally, the United Nations Convention on the Law of the Sea (UNCLOS, 1982) refers to invasive species in a general manner.[93] Article 196 states:

88. J. A. McNeely and F. Schutyser, ''Invasive Species: A Global Concern Bubbling to the Surface,'' Presented at the International Conference on the Impact of Global Environment Problems on Continental and Coastal Marine Waters, Geneva, Switzerland, 16–18 July 2003.

89. Doelle, n. 19 above, at 261–294.

90. D. Simberloff, ''How Much Information on Population Biology Is Needed to Manage Introduced Species?,'' *Conservation Biology* 17, 1 (2003): 83–92.

91. *Id.*

92. *Id.*

93. M. L. McConnell, ''Ballast and Biosecurity: The Legal, Economic and Safety Implications of the Developing International Regime to Prevent the Spread of Harmful Aquatic Organisms and Pathogens in Ships' Ballast Water,'' *Ocean Yearbook* 17, eds. E. Mann Borgese, A. Chircop and M. McConnell (Chicago: University of Chicago Press, 2003): 213–255.

> States shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, that may cause significant and harmful changes thereto.[94]

UNCLOS is the precursor to many more recent conventions and guidelines. The most recent is the IMO International Convention for the Control and Management of Ship's Ballast Water and Sediments (the Ballast Water Convention). Adopted in February 2004, it is based on guidelines created in 1997 that seek to minimize the transfer of harmful invasives.[95] The Ballast Water Convention defines the general rights and responsibilities of States along with treatment standards and sediment management.[96] The Convention on Biological Diversity (CBD), adopted in 1992,[97] includes a set of provisions that define conservation of biological diversity at the genetic, taxonomic and ecosystem levels.[98] This latter Convention is actually a treaty, a binding agreement that establishes goals rather than obligations,[99] e.g., Article 8(h), the Interim Guiding Principle for the Prevention, Introduction and Mitigation of Impacts of Alien Species.[100]

The United States currently has several federal acts that deal with non-indigenous species,[101] and four are briefly discussed here. The Lacey Act addresses intentional introductions and regulates species such as wild mammals, birds, fish and some invertebrates, including eggs and offspring that could be considered injurious to humans or important resources, such as agriculture, horticulture, forestry or wildlife. The Act prohibits the importation of species identified on its ''blacklist'' that currently includes a

94. United Nations Convention on the Law of the Sea (UNCLOS) 1982.

95. M. L. McConnell, ''GloBallast Legislative Review—Final Report,'' *GloBallast Monograph Series No. 1,* (London: IMO, 2002).

96. McConnell, n. 93 above, at 213–255.

97. Bax et al., n. 1 above, at 313–323.

98. L. Glowka and C. de Klemm, ''International Instruments, Processes, Organization and Non-Indigenous Introductions: Is a Protocol to the Convention on Biological Diversity Necessary?,'' in: *Invasive Species and Biodiversity Management,* O. T. Sandlund, P. J. Schei and Å. Viken, eds., (Dordrecht: Kluwer Academic Publishers, 1999): 389–405.

99. *Id.*

100. L. Glowka, ''Bioprospecting, Alien Invasive Species, and Hydrothermal Vents: Three Emerging Legal Issues in the Conservation and Sustainable Use of Biodiversity,'' *Tulane Environmental Law Journal* 13 (2000): 329–360.

101. V. Nadol, ''Aquatic Invasive Species in the Coastal West: An Analysis of State Regulation within a Federal Framework,'' *Environmental Law* 29, 2 (1999): 339–375.

mollusc and a crustacean.[102] The National Invasive Species Act (NISA) is an amendment to certain provisions of the Non-Indigenous Aquatic Nuisance Prevention and Control Act (NANPCA), which broadens policy beyond the Great Lakes focus of NANPCA to include national considerations. NISA established rules and policies for ballast water exchange by ships prior to their entry into the Great Lakes. In addition, it required ballast water management programs to employ technologies and practices that prevent introductions, it made new funding available through a new clearinghouse for national ballast water data and authorized research on the prevention and control of aquatic invasive species in Chesapeake Bay, the Gulf of Mexico and along the Atlantic coast. Unfortunately, NISA failed to overcome some important problems associated with the NANPCA. The ballast exchange process is mandatory only in the Great Lakes, and there are no voluntary ballast water guidelines for other national regions.[103] Further, NISA has insufficient funding to implement the requirements and it lacks enforcement mechanisms for non-compliance.[104]

Arguably, the contemporary benchmark policy for the control of invasive species in the United States is President Clinton's 1999 Executive Order 11312.[105] The Order attempts to correct shortcomings in earlier legislation by establishing a comprehensive co-ordination to prevent the introduction of invasive species via the National Invasive Species Council that in 2001 developed the National Invasive Species Management Plan, designed to coordinate federal efforts in the prevention, detection and rapid response to any introductions.[106]

Invasive species policy in the United States appears to fall short of adequately regulating the introduction of alien species because regulation is based on voluntary compliance, it is focused on activities instead of environment, and federal policy effectively ignores all vectors other than ballast water.[107] The United States is presently reviewing the National Aquatic Invasive Species Bill 2003, designed to amend and improve the NANPCA and the NISA. The Bill seeks to regulate issues that include vectors other than ballast water; regions other than the Great Lakes; and treatment methods for ballast water. The National Aquatic Species Bill 2003 was at the

102. Doelle, n. 19 above, at 261–294.

103. S. B. Zellmer, ''The virtues of 'Command and Control' Regulation: Barring Exotic Species from Aquatic Ecosystems,'' *University of Illinois Law Review* 2000, 4 (2000): 1233–1285.

104. Nadol, n. 101 above, at 339–375.

105. Available online: <http://ceq.eh.doe.gov/nepa/regs/eos/eo13112.html>; Doelle, n. 19 above, at 261–294.

106. *Id.*

107. Nadol, n. 101 above, at 339–375.

hearing stage during the preparation of this article; its final provisions and enactment remain to be determined.[108]

State legislation in the United States can be enacted to provide regulatory alternatives to omissions in federal legislation, but regardless of such efforts, no truly effective regulatory structure for invasive species management can exist without a comprehensive federal role. California provides a comprehensive state response to invasive species,[109] though functional difficulties exist, including a lack of coordination with neighbouring states in the event of species introduction and spread, a lack of provisions to address pathogens or viral invasions, and a lack of direction regarding eradication or mitigation measures in the event of an invasive establishment.[110]

The Canadian approach to the aquatic invasives problem can be viewed as inconsistent, piecemeal, uncoordinated, delayed and devoid of a comprehensive regulatory structure.[111] The jurisdiction for aquatic invasive species lies with the federal government and its constitutional authority over fisheries, shipping and its obligation to maintain ''peace, order and good government.''[112] No less than five laws under various jurisdictional agencies pertain to aquatic invasive species:

(1) the Fisheries Act (1985);

(2) the Canada Shipping Act (1985);

(3) the Canadian Environmental Protection Act (CEPA, 1999);

(4) the Canadian Environmental Assessment Act (1992); and

(5) the Wildlife Animal and Plant Protection and Regulation of International and Interprovincial Trade Act (1992).[113]

Additionally, there are two policies that address invasives:

(1) Guidelines for the Control of Ballast Water Discharge from Ships in Waters under Canadian Jurisdiction (2000); and

(2) Biodiversity Strategy (1995).

The Fisheries Act is the legislation with the greatest capacity to address threats from aquatic invasives,[114] where Fisheries and Oceans Canada (DFO)

108. Senate Committee on Environment and Public Works, Subcommittee on Fisheries, Wildlife and Water, *U.S. Senate Committee on Environment and Public Works Hearing Statements* S. 525 (2003).

109. Nadol, n. 101 above, at 339–375.

110. *Id.*

111. Doelle, n. 19 above, at 261–294; Nadol, n. 101 above, at 339–375.

112. *Id.* at 273.

113. *Id.* at 261–294.

114. *Id.*

has jurisdictional responsibility for licensing and controlling intentional introductions, as well as sanctioning unintentional introductions where they are deemed to be deleterious to fish or fish habitats.[115]

The overarching policy for invasives in Canada rests with the Canadian Biodiversity Strategy.[116] The Canadian Biodiversity Strategy requires database development for identification, monitoring, risk assessment, eradication and research measures relating to invasive species.[117] In September 2001, the federal government identified invasive species as a priority under the Strategy whenever a multi-layered collaborative effort on the part of government has been adopted to tackle the issue. The aim is to develop a National Action Plan on Invasive Species with DFO as the agency responsible for addressing the aquatic invasive species portion of the plan. DFO's mandate is thus to determine the primary routes of entry and spread of aquatic invasive species in Canadian waters, highlight fragile ecosystems, conduct risk assessments, and recommend specific actions that can be taken by the various jurisdictions. At time of writing this article, the plan remains a draft.[118]

In 2000, Canada developed Guidelines for the Control of Ballast Water Discharge from Ships in Waters under Canadian Jurisdiction.[119] These voluntary guidelines were proposed to implement the International Maritime Organization's resolution A.868(20), "Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens" in waters under Canadian jurisdiction.[120]

As with contemporary international policy, these Guidelines do not address the potential risks of NOBOB vessels.[121] In addition, the Guidelines for the Control of Ballast Water Discharge and the Canadian Biodiversity Strategy are policy-based initiatives and may lack the effectiveness of legislated regulatory measures with respect to compliance and enforcement.[122]

Canadian environmental policy does recognise the need to take action in situations where there is a paucity of data. The precautionary principle is

115. Fisheries Act, R.S., c. F-14, ss. 34–43, 1985.
116. Doelle, n. 19 above, at 261–294.
117. *Id.*
118. DFO (Fisheries and Oceans Canada) *Government Response to the 4th Report of the Standing Committee on Fisheries and Oceans—Aquatic Invasive Species: Uninvited Guests,* (Ottawa: Fisheries and Oceans, 2003).
119. Transport Canada, The Guidelines for the Control of Ballast Water Discharge from Ships in Waters Under Canadian Jurisdiction, (Ottawa: Transport Canada, 2001).
120. *Id.*, section 5.1.
121. Drake et al., n. 30 above, at 560–565.
122. Doelle, n. 19 above, at 261–294.

explicitly identified in both the Oceans Act and in the Canadian Environmental Protection Act.[123] In an adaptation of Principle 15 of the Rio Declaration, the Canadian Environmental Protection Act asserts that the Government of Canada will

> exercise its powers in a manner that . . . applies precautionary principle where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. . . . [124]

The keyword here may be ''cost-effective,'' perhaps suggesting an imperative for accurate accounting in terms of expected cost of treatment and the cost of no action. In 2000, Canada initiated the consistent application of the precautionary approach in all federal science-based regulatory programs to strengthen risk management practices. A discussion paper with guiding principles has been finalized and mechanisms are being implemented in various federal departments to adopt the new principles.[125] A precautionary approach, coupled with contemporary assessments and management techniques, should help to bridge gaps and lead to more effective identification of invasive species and their control.

Assessment and Control

Management actions for invasive species include prevention, early detection, control management and restoration, research and monitoring, and partnership efforts (National Invasive Species Council 2001).[126] Science can provide information on:

(1) the nature and extent of threats;

(2) the patterns of invasive distribution;

(3) methods of dispersal;

123. Oceans Act, R.S., c. 31 preamble and section 30, 1996; Canadian Environmental Assessment Act, R.S., c. 33, section 2(1)(a) and section 6 (1)(1), 1999.

124. United Nations Conference on Environment and Development, *Agenda 21: Programme of Action for Sustainable Development; Rio Declaration on Environment and Development, United Nations Conference on Environment and Development (UNCED), 3–14 June 1992, Rio de Janeiro, Brazil* (New York, UN Dept. of Public Information) 1993. 294 p; Canadian Environmental Assessment Act, n. 123 above.

125. Environment Canada, ''A Canadian Perspective on the Precautionary Approach/Principle,'' available online: <http://www.ec.gc.ca/econom/pp_e.htm>.

126. National Invasive Species Council, n. 3 above.

(4) economic costs;

(5) management methods; and

(6) enumeration of contemporary ''hot'' spots.[127]

All can contribute to informed management decisions and to reduced risk of aquatic invasions.

As noted above, much attention has been concentrated on the management of invasive species transported through shipping activities. At present, the only internationally approved ballast water management practice is that of ballast water exchange (BWE),[128] as recommended by the IMO Ballast Water Convention. Open ocean BWE involves replacing coastal water with oceanic water during a voyage,[129] either by emptying and refilling ballast tanks (sequential exchange) or by continuous or sequential flow-through dilution (three-fold tank volume).[130] Both methods can achieve 95 percent water exchange.[131] Oceanic BWE is not always biologically effective and can compromise ship safety (stability).[132] Continuous dilution helps circumvent safety problems though there can be an increase in time and cost to the shipper.[133] Safety and operational concerns about BWE and uncertainties in biological effectiveness have compelled the consideration of other ballast water treatment and management methods that complement or replace BWE and are more effective (Table 5).

We know of no internationally sanctioned evaluation standards for the formal acceptance of emerging techniques.[134] Prototype ballast water treatment technologies surveyed and certified by IMO are required to be

127. A. Ricciardi and J. B. Rasmussen, ''Predicting the Identity and Impact of Future Biological Invaders: A Priority for Aquatic Resource Management,'' *Canadian Journal of Fisheries and Aquatic Sciences* 55 (1998): 1759–1765.

128. International Maritime Organization (IMO). The IMO Guidelines, Resolution A.868 (20), Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens, 1997, 17 p.

129. International Maritime Organization, 2004, n. 14 above.

130. Endresen et al., n. 21 above, at 615–623; M. A. Champ, ''Economic and Environmental Impacts on Ports and Harbours from the Convention to Ban Harmful Marine Anti-Fouling Systems,'' *Marine Pollution Bulletin* 46 (2003): 935–940.

131. G. Rigby and A. H. Taylor, ''Suggested Designs to Facilitate Improved Management and Treatment of Ballast Water on New and Existing Ships,'' Discussion Paper prepared for the Australian Quarantine and Inspection Service, Research Advisory Group Ballast Water Research Programme-Australia. Report Series No. 12. 2000.

132. Endresen et al., n. 21 above, at 615–623; Champ, n. 130 above, at 935–940; Rigby et al., n. 131 above.

133. Endresen et al., n. 21 above, at 615–623.

134. International Maritime Organization, 2004, n. 14 above.

Table 5.—Internationally Proposed Ballast Water Management Methods and Preliminary Evaluation, State Water Resources Control Board and U.S. Environmental Protection Agengy

Treatment/Management Technology			*Safety*	*Biological Effective-ness*	*Environmental Acceptability*
Exchange		Empty and refill exchange	A	N	N
		Flow-through exchange	A	N	N
Treatment	Mechanical	Filtration	A	P	A
		Cyclonic separation	U	U	U
	Physical	Thermal	U	U	U
		Ultraviolet	U	U	U
		Ultrasound	U	U	U
		Magnetic fields	U	U	U
		Ozone	U	U	U
		Pulse Plasma	U	U	U
		Deoxygenation	U	U	U
	Chemical	Oxidizing biocide	U	U	U
		Antifouling coating	A	P	P
Isolation		Onshore treatment	A	A	A
		Return to origin	U	U	U

A—Acceptable P—Partially acceptable N—Not acceptable U—Unknown

Source: State Water Resources Control Board/California Environmental Protection Agency (SWRCB/CEPA), Evaluation of Ballast Water Treatment Technology for Control of Nonindigenous Aquatic Organisms, 2002. 76 pp.

safe to ship and crew, environmentally friendly, biologically effective, compatible with ship design and operation, and cost-effective.[135]

Most national and regional ballast water management regulations are modeled on IMO (voluntary adherence) guidelines.[136] If ballast water is ''clean'' (e.g., free of oil pollution), legislation does not exist to prevent species introductions unless nations adopt the guidelines.[137] A variety of

135. *Id.*
136. International Maritime Organization, 1997, n. 128 above.
137. G. M. Hallegraeff, C. Bolch, B. Koerbin and J. Bryan, ''Ballast water: a danger to aquaculture,'' *Australian Fisheries* 47, 7 (1988): 32–34.

methods are available to address fouling of the outer structure of a vessel, including chemical treatments and mechanical harvesting. Chemical agents such as organo-mercury compounds, lead, arsenic and DDT were used as antifouling treatments on vessel hulls and marine infrastructure until they were shown to pose severe environmental and human health risks and were subsequently withdrawn in the early 1960s.[138] The first use of organotin (TBT) antifouling paints began in the early 1970s and by the mid-1980s they were found to adversely effect non-target organisms such as oysters and snails. Environmental regulations ensued that limited the usage and release rate of antifouling paints containing TBT. In 2001, the IMO Convention on Control of Harmful Anti-fouling Systems on Ships banned the use of TBT in antifouling paints. The convention enters into force 12 months subsequent to ratification by 25 nation states representing 25 percent of the world's merchant fleet tonnage. The convention will require that ships not apply, or re-apply, organotins, shall not bear such compounds on their hulls or external parts or surfaces, or shall bear a coating that forms a barrier to such compounds leaching from the underlying non-compliant anti-fouling systems.[139] Chemical treatment of recreational vessels is less common; strategies to control the spread of invasives via recreational boating include mechanical hull cleaning and anti-fouling programs along with educational programs for boat owners and operators to prevent the spread of invasives from one ecosystem to another.[140] Likewise, mechanical harvesting is most frequently used to address the threat of invasives in ballast tank sediments.[141] However, this process does necessarily kill the organisms and if discarded offshore, currents can conceivably carry them back to coastal waters.

Establishing policies and regulations on shipping-related vectors is necessary though arguably insufficient for addressing all invasives as few studies address other vectors. A generalized policy to control marine invasives would include exclusion, eradication, containment, mitigation and adaptation.[142] Early detection (monitoring) and eradication (using biological control, chemical agents, traps, mechanical harvesting etc.) should prove to be the optimum methods for mitigation. However, some methods and

138. Evans et al., n. 32 above, at 204–211.

139. IMO press release, ''IMO adopts Convention on Control of Harmful Anti-Fouling Systems on Ships,'' available online: <http://www.imo.org/Newsroom/mainframe.asp?topic_id=67%doc_id=1486>.

140. Land and Water Resource Council (LWRC), n. 47 above.

141. J. M. Kelly, ''Ballast Water and Sediments as Mechanisms for Unwanted Species Introductions into Washington State,'' *Journal of Shellfish Research*, 12, 2 (1993): 405–410.

142. C. Perrings, ''Biological Invasions in Aquatic Systems: The Economic Problem,'' *Bulletin of Marine Science* 70, 2 (2002): 541–552.

agents have the capacity to impact native ecosystems in unpredictable and deleterious ways.[143] Unexpected outcomes, including poisoning non-target species, bioaccumulation of chemicals in the food chain, ineffective control of the target species, and habitat alteration or destruction become increasingly likely as the variety of methods and agents and variety of interacting invaders (and complexity of the ecosystem) increases.

Biological control introduces natural enemies to control invasive species and can include parasitoids, predators, pathogens, antagonists or competitor populations. While extensive research on biocontrol in terrestrial agro-ecosystems has been done, little is known about its application to the marine environment. Although biological control has been successful in eradicating invasive species in terrestrial agro ecosystems resulting in economic benefits, numerous establishments have not had the desired effect on pest organisms and may have caused adverse effects on non-target native species.[144] In recent years, biological control has also come to include genetic alteration of populations to interrupt reproductive cycles. The effectiveness of biological control is widely debated; it is difficult to predict the effects of biological agents before their introduction and host-specificity tests are not necessarily designed to quantitatively predict impacts on non-target species or to predict outcomes alternate to the one desired. In addition, biological agents can evolve (adapt) and move to alternative and native hosts.[145] While several principles apply to both terrestrial and marine environments, marine systems differ with respect to the types of control agents available, the spatial scale for which biocontrol must operate effectively, the degree of pest-population reduction required for effective control, the practicality of implementation, and the nature and degree of

143. R. E. Thresher, M. Werner, J. T. Hoeg, I. Svane, H. Glenner, N. E. Murphy and C. Wittwer, ''Developing the Options for Marine Pests: Specificity Trials on the Parasitic Castrator, *Sacculina Carcini*, against the European Crab, *Carcinus Maenus*, and Related Species,'' *Journal of Experimental Marine Biology and Ecology* 254 (1) (2000): 37–51; S. M. Louda and P. Stiling ''The Double-Edged Sword of Biological Control in Conservation and Restoration,'' *Conservation Biology* 18, 1 (2004): 50–53; E. S. Zavaleta, R. J. Hobbs and H. A. Mooney, ''Viewing Invasive Species Removal in a Whole-Ecosystem Context,'' *Trends in Ecology and Evolution* 16, 8 (2001): 454–459; Thomas et al., n. 4 above, at 325–329; Evans et al., n. 32 above, at 204–211.

144. D. J. Greathead, ''Benefits and Risks of Classical Biological Control,'' in H. M. T. Hokkanen and J. M. Lynch, eds., *Biological Control: Benefits and Risks* (Cambridge: Cambridge University Press, 1995), 53–60; D. Simberloff and P. Stiling, ''Risks of Species Introduced for Biological Control,'' *Biological Conservation* 78, 1–2 (1999): 185–192.

145. Thresher et al., n. 143 above, at 37–51; Thomas et al., n. 4 above, at 325–329; Louda et al., n. 121 above, at 50–53; D. E. Pearson and R. M. Callaway, ''Indirect Effects of Host-Specific Biological Control Agents,'' *Trends in Ecology and Evolution* 18, 9 (2003): 456–461; M. S. Hoddle, ''Restoring Balance: Using Exotic Species to Control Invasive Exotic Species,'' *Conservation Biology* 18, 1 (2004): 38–49.

concern for safety.[146] Implementation of biological control agents in marine environments has had varying levels of success. For example, parasitic castration has been identified as a possible control agent for the European green crab,[147] but little is known of its efficacy. Aquaculture industry experiments to induce infertility in Pacific oyster (*Crassostrea gigas*) report 20 percent of the individuals rendered triploid (thus infertile) reverted to diploid, thus there is considerable doubt about the effectiveness of such a treatment.[148]

Risk Analysis

Management priorities, ordered in the face of an analysis of risk, can help determine the most effective use of funds and effort in addressing invasive species issues. Management must be prepared to establish priorities ''under conditions of incomplete information about the set of possible invaders, the likelihood of their introduction, establishment and spread, and the potential damages if they do.''[149] As previously noted, invasive-control management is challenging in part due to uncertainty,[150] but modeling to parameterize uncertainties and gauge their relative influence on the outcome can help to choose the most promising courses of action.[151] Risk assessment can facilitate the consideration of alternative treatments, open dialogue, and broaden public understanding of the issues.[152]

Compiling pre-invasion data can be a costly and unreliable exercise for predictive purposes,[153] and thus risk assessment may have to rely on flexible valuation techniques to define the specific value of vulnerable areas or the assessment of potential damage. A technique similar to the ''contingent

146. Lafferty et al., n. 4 above, at 1989–2000.
147. Thresher et al., n. 143 above, at 37–51.
148. G. Shatkin, S. Shumway and R. Hawes, ''Considerations Regarding the Possible Introduction of the Pacific Oyster (*Crassostrea Gigas*) to the Gulf of Maine: A Review of Global Experience,'' *Journal of Shellfish Research* 6, 2 (1997): 463–477.
149. R. D. Horan, C. Perrings, F. Lupi and E. H. Bulte, ''Biological Pollution Prevention Strategies under Ignorance: The Case of Invasive Species,'' *American Journal of Agricultural Economics* 84, 5 (2002): p. 1303.
150. D. Simberloff and P. Stiling, ''Risks of Species Introduced for Biological Control,'' *Biological Conservation* 78(1–2) (1996): 185–192.
151. E. Slooten, D. Fletcher and B. L. Taylor, ''Accounting for Uncertainty in Risk Assessment: Case Study of Hector's Dolphin Mortality Due To Gillnet Entanglement,'' *Conservation Biology* 14, 5 (2000): 1264–1270.
152. Laffery et al., n. 4 above, at 1989–2000.
153. M. H. Thomas and A. Randall, ''Intentional Introductions of Nonindigenous Species: A Principal-Agent Model and Protocol for Revokable Decisions,'' *Ecological Economics* 34 (2000): 333–345.

valuation'' survey-based process currently used for environmental valuation in economic terms may be adapted for informed decision-making regarding invasives.[154] A quantitative ecological risk assessment, similar to those used in the nuclear and chemical process industries, has been proposed to evaluate the effectiveness of new technologies such as ballast water management strategies.[155] With a cadre of such tools in hand, managers can develop priorities for those situations where they have determined a high probability for success, where they can choose the response most likely to provide the greatest success, and where the funds and effort required can be known. The consequences of the management decision(s) must be routinely documented if the decision-making process is to successfully evolve toward one that is functional, efficient and timely.

Partnerships and Cooperation

The problems posed by invasive species often involve two or more parties (countries, regions, agencies etc.), often with uncertain consequences. Non-existent, delayed or ineffective coordination among parties serves only to undermine the efficiency of assessment and management.[156] Formal partnerships improve cooperation and provide a mechanism to organize efforts. The recent Ballast Water Convention highlights the effectiveness of establishing partnerships and cooperation among countries.[157] Such arrangements can lead to:

(1) proposition of additional regulations for a more effective prevention of invasions;

(2) the assignment of priorities and responsibilities to avoid the duplication of measures and resources; and

(3) enhanced funding availability to help build capacity.[158]

154. J. van den Bergh, P. Nunes, H. M. Dotinga, W. Kooistra, E.G. Vrieling and L. Peperzak, ''Exotic Harmful Algae in Marine Eco-Systems: An Integrated Biological-Economical-Legal Analysis of Impacts and Policies,'' *Marine Policy* 26 (2001): 59–74.

155. K. R. Hayes, ''Ecological Risk Assessment for Ballast Water Introductions: A Suggested Approach,'' *ICES Journal of Marine Science*, 55 (1998): 201–212.

156. A. M. Perrault and W. C. Muffett, ''Turning off the tap: A strategy to address international aspects of invasive alien species,'' *Review of European Community and International Law* 11, 2 (2002): 211–224.

157. IMO (International Maritime Organization), *International Convention for the Control and Management of Ships Ballast Water and Sediments,* adopted 13 February 2004, available online: <http://www.imo.org/home.asp>.

158. A. Dextrase, ''Preventing the Introduction and Spread of Alien Aquatic Species in the Great Lakes,'' in *Alien Invaders in Canada's Waters, Wetlands and Forests,* Claudi et al., eds. (Ottawa: Natural Resources Canada and Canadian Forest Service, 2002): 219–231.

International organizations do exist that provide more comprehensive response to global concerns. Such organizations can be enlisted to foster collaborative efforts regarding invasive species. Organizations such as the United Nations Environment Programme (UNEP), IMO, the Food and Agriculture Organization (FAO), the Secretariat for the Convention on Biological Diversity (CBD) and the World Conservation Union (IUCN) have varying nation-state memberships, although they all appear to encourage cooperation and collaboration in many domains. An independent but international body could coordinate information collection across many aspects of invasive species including taxonomy, ecological interrelationships, resource contacts, and methods of control, etc.[159]

The Global Invasive Species Program (GISP) is an international program dedicated solely to invasive species issues, and has the IUCN and CBD as member-partners. The GISP strives to improve the scientific bases for decision making, to develop capacity for early warning and rapid assessment and response, to enhance invasive management capability, to reduce economic impacts of invasives and to develop better risk assessment, and strengthen international agreements.[160] GISP provides the ways and means for achieving high-level discussions on the sharing of information and the adoption of best practices, but additional direction is required to translate the work done by GISP into effective regional management techniques. Developing functional links between local cooperating institutions along with national and international planners is necessary for cross-border invasive species management.[161] The North American Commission for Environmental Cooperation (CEC), composed of the senior governmental officials responsible for the environment in Canada, Mexico and the United States, is an example of international collaboration to address environmental concerns, including invasive study and response.[162] The CEC is currently involved in a project to develop prevention and control measures to eliminate pathways in coastal and fresh waters of North America, and has created a comprehensive overview of available scientific and policy information for the North American region.[163] The CEC aims to

159. The World Conservation Union (IUCN), Position Statement on Translocation of Living Organisms: Introductions, Reintroductions and Re-Stocking, approved by the 22nd Meeting of the IUCN Council, Switzerland, 4th September 1987.

160. Global Invasive Species Programme, available online: <http:www.gisp.org/>.

161. A. Grosse and B. Gregg, ''Invasive Species as a Trilateral Challenge,'' *Report on the Plenary Session at VIII Trilateral Committee Meeting, Albuquerque, New Mexico* (2003).

162. The Commission for Environmental Cooperation (CEC), available online: <http://www.cec.org/who_we_are/index.cfm?varlan=english>.

163. The Commission for Environmental Cooperation (CEC), available online: <http://www.cec.org/programs_projects/conserv_biodiv/project/index.cfm?projectID=20&varlan=english>.

identify common aquatic invasive issues and pathways, develop a North American Invasive Species Information Network and a directory of legal institutions, and identify and develop tools for raising awareness and capacity in decision makers, as well as compliance incentives for the industrial and economic sectors.[164] Although created in 1993 under the North American Agreement on Environmental Cooperation (NAAEC), the CEC only began to address invasive aquatic species in 2001 and has to date held three meetings to address invasive aquatics. Thus, this partnership is in the early stages of developing collaborations to address invasive concerns.[165] As summarized above, a cohesive action plan for Canada is still under development, although according to its Biodiversity Office, Environment Canada has become the lead agency for an inter-departmental Canadian effort to address invasive species.[166] Functional implementation among the various federal agencies is not complete and so the utility of the initiative remains to be seen.

At the regional level, awareness programmes such as the one coordinated by the Ontario Federation of Anglers and Hunters, in partnership with the Oshawa Creek Watershed Committee and the Ontario Ministry of Natural Resources represents a cooperative example of defining the problem for the resource users and policy makers alike.[167] Similarly, the partnership created between the State of Washington (United States) and Province of British Columbia (Canada) has been instrumental in the sharing of information and the initiation of activities focussed on the prevention of invasions.[168] Partnerships between government and community groups can help to adapt comparatively ambiguous policy to very specific practices appropriate to the location or invasive concern.

CONCLUSIONS AND RECOMMENDATIONS

Management decisions must provide realistic goals and objectives that balance available resources with the plausibility of obtaining effective control over the target problem, on a case-by-case basis. This requires a proactive ideology and a capacity to predict, with uncertainty, the outcome of a decision along with a determination of which potential consequences are most desirable for a given situation. Recent arguments introduced in

164. The Commission for Environmental Cooperation (CEC), available online: <http://www.cec.org/files/pdf/BIODIVERSITY/225–03–05_en.pdf>.
165. *Id.*
166. Environment Canada, Biodiversity Convention Office, 2004, n. 7 above.
167. Central Lake Ontario Conservation Agency, available online: <http://www.cloca.com/news/news2004/alien%20workshop.pdf>.
168. Doelle, n. 19 above, at 261–294.

Addressing the Threat of Invasive Alien Species: A Strategy for Canada (March 2004)[169] suggest that Canada will concentrate on setting response priorities and will attempt to balance costs and benefits against the probability for success. Judicious priority setting will require the ability to predict likely outcomes of decisions, and the ability to modify decisions as more information is received. These are elements that are recognized by the authors of the strategy as they petition for the evolution of invasives management ''from a reactive to a predictive discipline,''[170] and we would add from reactive to proactive.

Contemporary management of invasives has low capability and poor predictive skill regarding the species that pose the greatest threat, which environments are most vulnerable, and what the economic or environmental impacts of an invasion will be. We offer suggestions in two principal areas that should lead to increased capability and predictability:

(1) Improve the technology and scientific knowledge relevant to the problem.

  (a) Advance the scientific data and modeling techniques required to assess impacts of invasives. Begin with what limited data there are to determine where the lacunas lie and monitor the evolution of known invasives and any/all mitigation measures.

  (b) Use the existing scientific literature and ancillary information to anticipate particularly vulnerable communities where effort might be concentrated.

(2) Improve the coordination of effort, information sharing and standardizations (where warranted).

  (a) Achieve internationally accepted, scientifically sanctioned and functional protocols for detection, assessment, control implementation, or evaluation of control efficacy where perfection is not the primary goal.

  (b) Achieve effective coordination of effort and information sharing across all engaged institutions (including industry) at the national and international level.

  (c) Achieve legislated regulations that go beyond the strictly voluntary and are designed with the motivational bases commensurate with predictably high levels of compliance.

It is generally accepted that managers will rarely have the luxury of making decisions regarding invasives with complete information and high

169. Environment Canada, Biodiversity Convention Office, 2004, n. 7 above.
170. *Id.* at 26.

predictive skill. In the absence of complete information, the choice of an appropriate management response will require the guidance provided by a clear, proactive policy, well constructed risk assessment procedures, sound documentation and the support of effective and fully functional collaborative efforts.

International initiatives including the IMO Ballast Water Convention,[171] the Convention on Biological Diversity,[172] and Agenda 21[173] represent important keys to guiding an effective response to a global concern. In the case of ballast water, an overall strategy based on a range of management and treatment options is the generally accepted approach, at least for now. International guidelines are needed for the regulation and safe use of invasive control measures, similar to the Biocontrol Code of Conduct.[174] International endorsement of practices can have significant influence on acceptance of those practices at the national level, and can expedite adoption into domestic policy. This has been shown in the recognition of the precautionary principle in some national policies in Canada, as well as in ballast water regulations in Canada and the United States, though comprehensiveness, clarity and enforceability regarding aquatic invasive law and policy in either country has yet to be achieved.

As the precautionary principle gains prominence in national policy at the rhetorical level and more desirably at the practical level, managers will rightfully and increasingly be called upon to make decisions in conditions of incomplete knowledge. Risk analysis practices, coupled with efficient and timely information sharing structures, including consequences recorded from previous or ongoing responses, can help to inform the decision bases, particularly if uncertainties are integral to the process. Techniques that model cost-accounting for assessment of potential ecological damages can place expected costs of control into context with the estimated costs of no response, where the latter also demands assessment.

The Canadian strategy for addressing invasive species addresses the necessary partnerships and the integration of data sharing and informed decision making,[175] but the ensuing action plans will determine the functionality of the concepts as they will in many respects in the United States. International, local and regional partnerships and collaborative efforts can provide the impetus *and* the support necessary to transform

171. McConnell, n. 95 above.

172. Bax et al., n. 1 above, at 313–323.

173. United Nations Conference on Environment and Development, n. 124 above, at 294.

174. A. Gassman, ed., *Profile: The IOBC Newsletter,* Issue 73 (Darmstadt, Germany: International Organization for Biological and Integrated Control of Noxious Animals and Plants Publication Commission, 2001).

175. Environment Canada, Biodiversity Convention Office, 2004, n. 7 above.

policy into practice. The work of the CEC, while still in its infancy, may prove to be invaluable to the environmental agencies of Mexico, the United States and Canada. Functional cooperation among local, regional, national and international institutions and planners also encourages the establishment and impetus for cross-border invasive species management.[176] Governmental priority and sustained fiscal resources will provide the level of motivation that is conducive for such initiatives and their cooperating agencies to realize the broader corporate objectives.

176. A. Grosse and B. Gregg, ''Invasive Species as a Trilateral Challenge,'' *Report on the Plenary Session at VIII Trilateral Committee Meeting. Albuquerque, New Mexico,* 2003.