Biological Invasions **6**: 295–300, 2004.

Options for managing invasive marine species

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Received 23 September 2003; accepted in revised form 30 October 2003

Key words: biological control, community attitudes, genetics, management strategies, marine pests, risk assessment

Abstract

Marine biological invasions are increasingly recognised as a threat to biodiversity and coastal industry, including fisheries. Globally, efforts are underway to contain, if not eradicate, several high-impact marine invasive species. However, working in a marine environment places unique social, political and technical constraints on options for pest control, which we explored in a series of stakeholder workshops. Results suggest that current efforts are low risk and publicly acceptable, but have a low probability of success against established invaders. However, techniques deemed likely to be successful and ultimately needed in a marine context are currently more contentious for social and political reasons. To control introduced marine pests, scientists and managers will need to overcome perceptual biases among marine stakeholders, develop a decision-making framework for what is perceived to be an open system, and focus on technologies likely to be both effective and publicly and politically acceptable.

Currently, efforts are in progress to eradicate outbreaks of the invasive marine alga, *Caulerpa taxifolia*, in California, the Mediterranean Sea and Australia (Meinesz et al. 2001; Cheshire et al. 2002; Williams and Grosholz 2002; Woodfield 2002), an Asian whelk, *Rapana venosa*, in Chesapeake Bay (Mann and Harding 2000) and an Asian mussel, *Perna viridis*, in Cairns, Australia. Control options are being considered for the European shore crab, *Carcinus maenas*, in the USA and Australia, for the Chinese mitten crab, *Eriocheir chinensis*, in California (as well as, historically, England and Germany), and for a host of other invasive marine species, ranging from seastars and ctenophores to shell-boring polychaetes and diverse algae, worldwide. As rates of marine bioinvasions continue to increase (Cohen and Carlton 1998), pressure will increase on marine managers to reduce the impacts of such invaders, and on scientists to provide control options (Bax et al. 2001).

There is a long history and extensive literature on managing terrestrial and aquatic invasive species, which should provide a firm basis for developing control options for marine invaders. However, there are four fundamental differences between marine and terrestrial ecosystems that potentially compromise these options (Lafferty and Kuris 1996; Thresher 2000; Kuris 2003).

1. The ocean is perceived by the public and managers as an open system, despite increasing evidence to the contrary for at least some species (Cowen et al. 2000; Sponaugle et al. 2002; Thresher et al. 2003). An emphasis in the technical and lay literature on global patterns of circulation, pelagic larvae, broadly distributed species and large-scale migrations fosters the perception that management actions undertaken at one location will ultimately affect large areas of coastline. This has three consequences. First, the 'not in my backyard' syndrome is easily triggered among marine stakeholders even for management actions some distance away (e.g., release of a biological control agent). Second, the perception exists that once a

pest is established in even a small area, currents will rapidly spread its larvae, making local eradication efforts (e.g., physical removal) fruitless. Third, assignment of the responsibilities, costs and benefits and the authority for decision making with regard to pest control are diffuse and often unclear (e.g., Meinesz and Thibault 1998).
2. The public perceives the ocean and open coastline to be essentially pristine, again despite often conspicuous evidence to the contrary (Janzen 1998; Jackson et al. 2002).
3. Coastal managers are typically defeatists with regards to prospects for pest management, largely because of the perceived open nature of the system (Kuris 2003).
4. Information on the biology of most marine taxa and communities is relatively limited, which increases scientific and public uncertainty about outcomes of control actions.

To assess the effect of these perceptions and constraints on prospects for long-term control of introduced marine pests, the Australian CSIRO Centre for Research on Introduced Marine Pests held workshops on three invasive species (the alga, *Undaria taxifolia*, the European shore crab, *C. maenas* and the seastar, *Asterias amurensis*) to canvas the strengths, weaknesses and prospects for possible control actions. Each workshop involved a diverse range of informed stakeholders, including representatives of marine conservation groups, the aquaculture and fishing industries, local, state and national marine managers, and Australian and international scientists with particular expertise on the species in question. As the final part of the workshop process, participants were asked to generate a list of potential control options, and then to assess their acceptability against a range of criteria and their likely efficacy in controlling, if not eradicating the species in question. The criteria for acceptability follows Norton (1983, 1988). After that, they were asked to assume that all the methods discussed were technically feasible, and then requested to rank control options in their order of acceptability.

A synthesis of the workshop results is given in Tables 1 and 2. Participants discriminated between short-term, small-scale control efforts, and those required for broadly distributed and well-established pests. They also considered community and political acceptability as separate but equally important issues, on the basis that the latter was unlikely without the former, and that no control effort was likely to get approval to commence if it had the potential for serious political damage if it went wrong.

The results of the evaluation and subsequent discussion with workshop participants indicate that the key criteria for ranking of acceptability were reversibility and the risks of non-remediable collateral damage.

Table 1. Perceived effectiveness and attractiveness of options for the control of introduced marine pests, as judged by workshop participants. Attractiveness was divided into five parameters, following Norton (1988). Y = Yes (meets criterion); N = No (does not meet criterion); ? = Uncertain; ?? = Very uncertain. Assessment of biocides was highly variable depending on the specificity of the toxin and the mode of delivery. Political acceptability of environmental remediation depended on the cost of remediation.

Method	Effectiveness	Acceptability criteria				
		Environmentally safe	Safe for human health	Practical	Social	Politically attractive
Physical removal	Small scale only, medium to high density	Y	Y	Y	Y	Y
Biocide	Small to medium scale only	Y?	Y?	Y?	Y/?/N	Y/?/N
Environmental remediation	?	Y	Y	?	Y	Y?
Biological control						
Augment native predators	??	?N	Y	?	Y	Y
Augment native parasite	Y?	Y?	Y	?	Y	Y
Introduce exotic predator	??	N	Y	?	N	N
Introduce exotic parasite or non-viral disease	Y?	Y	Y	Y	?N	?N
Introduce exotic virus	Y?	?	?	?	N	N
Genetic modification						
Of pest only	Y	Y	Y	?	?	?
Of native species	Y	?	?	Y?	??	??
Of virus/disease	?	?	?	?	N	N

Hence, workshop participants readily endorsed physical removal, which could easily be stopped and had no long-term consequences for the marine environment, but were uncomfortable with the prospect of, for example, introducing an exotic parasite to control even a major pest species. Such an introduction was seen by some as potentially compounding the problem (two exotic species rather than one), and irreversibly changing the 'pristine' local biota with uncertain consequences for other marine communities (the 'open ocean' mentality).

Table 2. Options for control of introduced marine pests, as ranked by the workshop participants. 1 = most acceptable.

1. Do nothing; the problem might go away.
2. Rehabilitate the environment, in the belief that pests are problems only in degraded areas.
3. Physically remove pests for new incursions or, if established, from important sites (fish farms, marine reserves) while ignoring the rest.
4. Encourage commercial utilisation.
5. Deploy pest-specific biocides, reproductive inhibitors etc.
6. Encourage native predators that attack the pest.
7. Deploy non-specific biocides, tactically applied.
8. Encourage native diseases and parasites that attack the pest.
9. Apply genetic approaches that affect only the pest.
10. Apply biological control, using exotic parasites.
11. Apply biological control, using exotic non-viral diseases.
12. Genetically modify native species (i.e., to use them as vectors for physiological inhibitors).

Not acceptable under any circumstances

13. Apply biological control, using exotic predators
14. Apply biological control, using exotic viruses
15. Genetically modify disease/virus to increase pathogenicity against pest

This bias is evident in current efforts to manage existing marine invaders. For both invasive plants and animals, studies on potential control options have focussed on biocides and physical control (Figure 1), both of which are easily localised and reversible. This bias is even more evident in attempts to date to control marine invasives (Figure 1). For both plants and animals, physical removal has been the dominant approach used. No efforts are under way to use alternative methods, such as biological control, and even recent studies on potential biological control agents have largely ceased due to lack of funding, in Australia, in the USA and in Europe.

The most striking outcome of the workshop deliberations was a strong negative relationship between the acceptability of a control option and the participants' estimate of its likelihood of succeeding against established pests (Figure 2). The specific results of the evaluation were scale-dependent. For small-scale

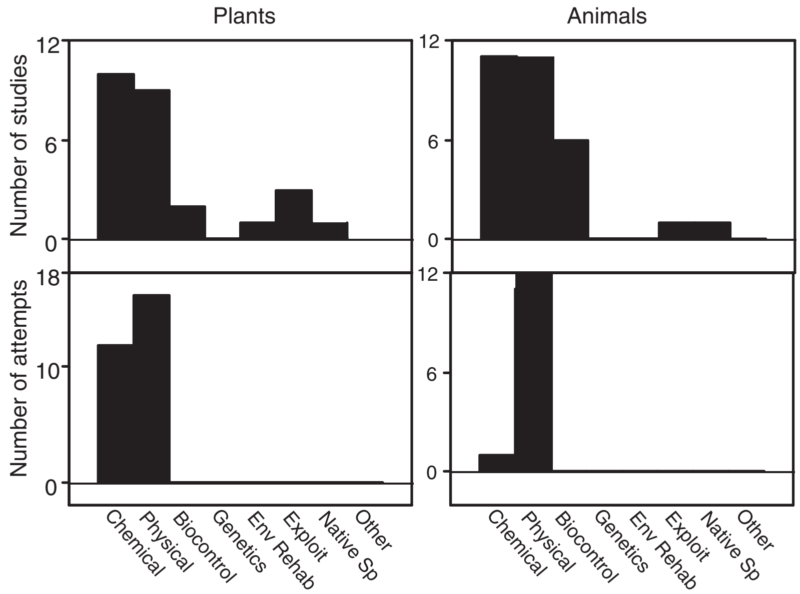

Figure 1. The distribution of studies on controlling introduced marine plants and animals and attempts to control them, through 2002, divided into seven broad categories (chemical control, physical removal, biological control involving exotic predators, herbivores, parasites or diseases, genetic technology, environmental remediation, commercial exploitation and augmentation of native predators, herbivores, parasites or diseases, plus an 'other' category). Data derived from an assessment of the grey and peer-reviewed literature, analysis of databases of scientific literature and personal communications from key individuals in the field. The compilation excludes the three workshops involved in this study.

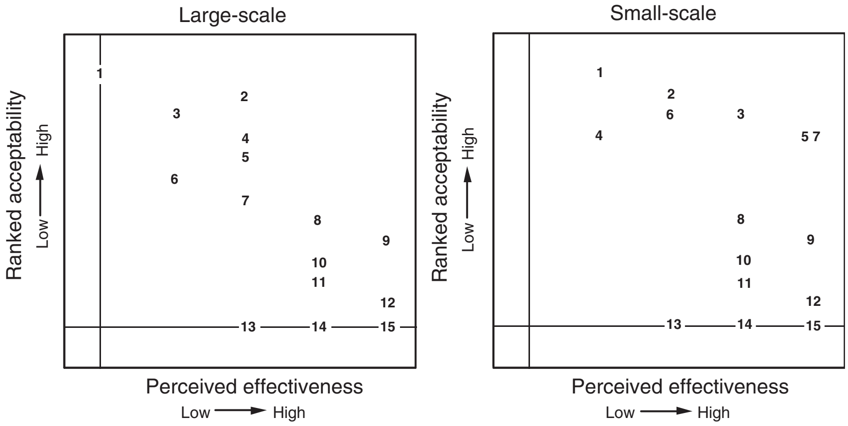

Figure 2. Scattergrams of the acceptability and effectiveness of control options listed in Table 2, as scored by workshop participants and based on subsequent discussions, for large (widely distributed pests) and small-scale (localised incursions) applications.

incursions, two options – physical removal and biocides (both pest-specific and non-specific) – were considered acceptable and probably effective (Figure 2). Success rates for control attempts to date appear to support these conclusions. There have been numerous successful physical eradications of very small ($< 5\ m^2$) patches of *C. taxifolia* in the Mediterranean Sea, but few successes using physical removal or biocides against larger, well-established patches (Meinesz et al. 2001). For other marine plants, attempts have either failed altogether or only slowed the rate of establishment (e.g., *U. pinnatifida* in Australia and New Zealand; *Sargassum muticum* in the UK; *Codium fragile* in Australia). For invasive marine animals, there are only three reports of successful eradication, all involving very localised incursions: physical removal of less than 20 mature bivalves (*P. caniculus*) in South Australia (J. Gilliland, pers. comm.), physical removal of the most susceptible native molluscan hosts for a South African sabellid (*Terebrasabella heteroucinata*) in California (Culver and Kuris 1999; Kuris 2003), and biocidal eradication of a bivalve (*Mytilopsis sallei*) in an enclosed lagoon at Darwin, Australia (Bax et al. 2002). The latter two eradications both involved millions of individuals of the exotic pests. Efforts to physically eradicate small numbers of another bivalve (*P. viridis*), at Cairns, Australia, appear to be succeeding, but sampling has yet to be completed. Physical removal is also being used to eradicate annually small numbers of *Sabella spallanzanii* re-introduced routinely into a few Australian ports from a large near-by source population. The decisions by coastal managers to use physical removal and biocides to attempt control of small-scale incursions appears to be appropriate, given the workshops' assessments of the acceptability and likelihood of success of the options available.

Effective options for widely established pests are less clear cut. At large space scales, no option discussed by the groups was even moderately acceptable and also judged likely to succeed. The negative relationship between acceptability and the likely efficacy of control options suggests three avenues for progress: develop new techniques that are both acceptable and effective, increase the effectiveness of acceptable techniques, or increase the acceptability of techniques deemed likely to be successful. Prospects for improving the efficacy of physical removal, biocides and environmental remediation appear to be limited. These approaches face daunting logistical difficulties working in a marine environment and may incur considerable collateral damage (from mechanical harvesting, for example). Dilution of biocides and the hardiness of many invasive species are also major impediments to efficacy of these methodologies. Encouraging commercial utilisation risks institutionalising a pest. With regard to increasing the acceptability of other options, workshop participants were strongly opposed to some technologies, such as use of exotic viruses, genetically modified viruses or generalist predators as control agents. The use of such techniques appears very unlikely in the near to medium term, even if they were technically feasible. Genetically modifying native species to either increase their resistance to invaders or to be vectors for a control agent, such as a biocide, was also considered of dubious acceptability.

Two control strategies appear to be potentially effective and, on the basis of the workshop evaluations, could become culturally acceptable: classical biological control and the use of genetic technology to decrease pest viability. Classical biological control, using natural enemies such as parasitoids and parasitic castrators, would be more acceptable if there was a credible evaluation of safety (host-specificity) and more evidence of efficacy (Lafferty and Kuris 1996; Kuris and Lafferty 2000). Recent analyses of the number of parasites of native and introduced populations of a wide range of plants and animals have confirmed that introduced populations generally have considerably fewer such natural enemies than do the introduced populations (Torchin et al. 2003; Mitchell and Power 2003). Green crab growth and abundance in Europe is substantially impacted by the prevalence of its native parasitic castrators (Torchin et al. 2001). However, uncertainty about the ultimate distributions of exotic control agents and, in some regions, the need for a decision-making process that spans other potentially affected jurisdictions may hamper this approach (Meinesz and Thibault 1998).

Of the techniques considered at the workshops, the one that participants felt had the most potential to be acceptable and effective was genetic modification of the pest species to reduce its viability. This opinion prevailed despite current public unease over GM technology and uncertainty about the technology itself. However, it was dependent on strong evidence that the genetic modification would remain confined to the pest species. In that regard, the prospects of both biological control and genetic approaches being accepted are likely to be highest where the targeted pest has no close relatives in invaded areas. This is often the case and should facilitate specificity by natural enemies in classic biological control and reduce the likelihood of gene transfer via hybridisation in genetic technologies.

Different cultures have different perceptions as to pest status, are more or less risk averse, (e.g., British vs USA attitudes towards genetically modified organisms), and may be inherently more or less proactive in dealing with environmental threats. These cultural differences will influence community and political willingness to attempt previously untried management strategies. Although the workshop participants came primarily from Australia, we think that the general tenor of the poll results are applicable elsewhere, but note that participants from other cultures may rank the control options somewhat differently. We also note that, over time, values change. In that light, we suggest that funding and management agencies consider the range of possibilities, rather than requiring future strategies to adhere to past norms, when deciding where to invest resources, that research have time frames long enough that innovative approaches can be advanced and expedient research eschewed, and that potential synergies among complementary approaches be assessed via modelling (e.g., management strategy evaluation) in the recognition that a 'silver bullet' for any particular pest is unlikely.

Acknowledgements

We thank the participants at the three workshops for their efforts and stimulating discussion, L. Goggin, R. Martin, C. Proctor and S. Spinks for assistance in organising the workshops, A. Meinesz for up-to-date information on the control of *C. taxifolia*, and N. Bax, C. Hewitt, K. Lafferty, G. Ruiz and M. Torchin for stimulating discussion and feed-back on these ideas.

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