A New Agenda for Science and Management of Estuarine and Coastal Invasive Species

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Managing Invasive Marine and Estuarine Species

- Managing invasive species in marine/estuarine systems has changed substantially over the past ten years
- The focus was entirely on prevention with little thought about established invaders
- Ships ballast was thought to be the primary if not the only important vector for coastal invasions

Managing Invasive Marine and Estuarine Species

- Older view was that eradication is unlikely or impossible in estuarine and marine systems
- Within in past ten years, several successful eradication programs have been conducted, three in CA
- Many other vectors including hull fouling, live bait and seafood, aquaculture may as, if not more, important than ballast water

A Summary of Invasions and Eradication Attempts

- Eradication and other management efforts in coastal systems have had been very uneven in use of scientific information
- The science undertaken in this area has rarely considered the information needs of resource managers
- Particular need to develop research priorities that will inform decisions about eradication of invasive marine/estuarine species

Talk the Talk

- Discuss past invasions, impacts and attempts at eradication
- Use two case studies, *Caulerpa taxifolia* (killer algae) in southern CA and hybrid *Spartina* in SF Bay to contrast science input
- Discuss the science “needs” expressed by coastal resource managers and compare these needs with those in terrestrial systems
- Outline a new agenda for management focused research

Major Functional Groups of Concern

Table 4 Examples from major functional groups of concern for estuarine and coastal introduced species and their effects

Type of Species	Example	Effect	Reference
Clonal or Weedy	*Caulerpa taxifolia* (seaweed)	Overgrows seagrasses	Ceccherelli and Cinelli 1997
	Caulerpa racemosa (seaweed)	Overgrows seagrasses	Ceccherelli and Campo 2002
	Watersipora subtorquata (bryozoan)	Fouls ship hulls and marinas	Floerl et al. 2004
Predator	*Carcinus maenas* (green crab)	Eats bivalves and crabs	Grosholz et al. 2000, 2001
	Rapana venosa (veined whelk)	Eats commercially important bivalves	Savini and Occhipinti-Ambrogi 2005
	Asterias amurensis (seastar)		Ross et al. 2002
Filter feeder	*Corbula amurensis* (Asian clam)	Reduces phytoplankton Correlates with zooplankton declines	Alpine and Cloern 1992; Kimmerer et al. 1994
Ecosystem Engineer	*Spartina alterniflora* (smooth cordgrass)	Converts mudflats; reduces shorebird foraging	Neira et al. 2005, 2006, 2007; Levin et al. 2006; Tyler et al. 2007
	Zostera japonica (Japanese eelgrass)	Converts mudflats	Posey 1988
	Crassostrea gigas (commercial oyster)	Creates reefs	Ruesink et al. 2005
	Musculista senhousia (Asian mussel)	Creates byssal mats in sediments	Crooks & Khim 1999

Examples of Economic Impacts of Marine/Estuarine Invasions

Table 1 Examples of economic impacts of introduced estuarine and marine species

Introduced Species	Economic Impact	Estimated Cost	Reference
Seaweeds			
Caulerpa taxifolia killer algae	Eradication	>US$6M (6 year)	Authors
Codium fragile v. *tomentosoides* oyster thief, deadman's fingers	Cultured oyster mortality, kelp valuation	C$1,500,000 /yr	Colautti et al. 2006
	Removal from native seaweed farm	Bankruptcy	Neill et al. 2006
Hypnea musciformis	Removal	US$55,000	Van Beukering and Cesar 2004
	Reduced property values		
Undaria pinnatifida Wakame	Eradication	NZ$2,923,500 (total)	Wotton et al. 2004
Invertebrates			
Carcinus maenas European green crab	Reduces bivalve aquaculture	US $22M/yr	Grosholz et al. 2000, Lovell et al. 2007
Eriocheir sinensis Chinese mitten crab	Invasion of fish salvage facility	US$1M (2000)	Aquatic Nuisance Species Task Force 2003
Mnemiopsis leidyi Ctenophore	Correlated loss of anchovy fishery	US$250M/yr	Zaitsev 1992
Mytilopsis sallei black striped mussel	Eradication	A$2.2M	Bax et al. 2002
Phyllorhiza punctata Scyphomedusa	Potential loss in shrimp landings	US$10M (2000)	Graham et al. 2003
Terebrasabella heterouncinata Sabellid polychaete	Reduced cultured abalone product quality	Bankruptcy	Culver and Kuris 2000
	Eradication	Several US$K	Kuris 2003
Teredo navalis Shipworm	Structural damage (ships, docks)	US$200M/yr	Cohen and Carlton 1995

Table 2 Examples of eradication programs for introduced estuarine and coastal marine species, listed in chronological order

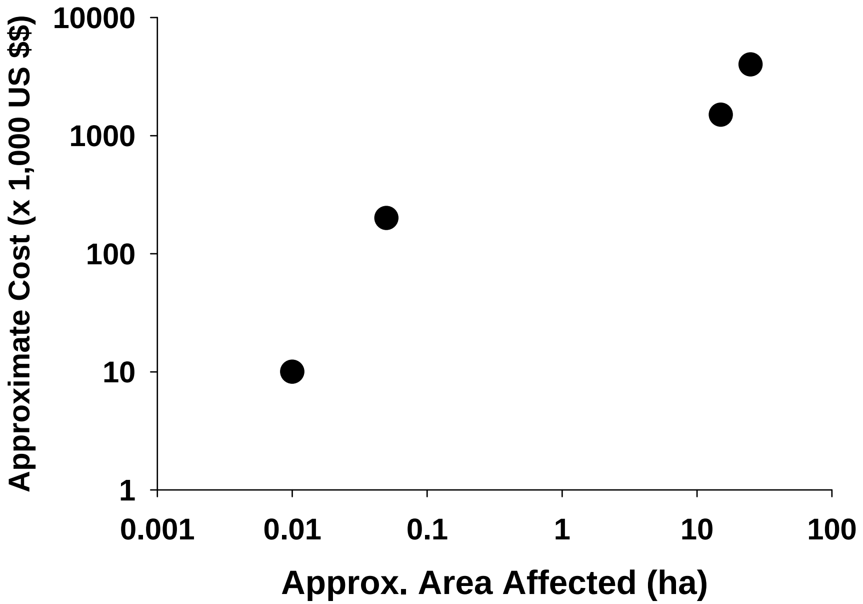
Introduced Species	Eradication Site	Date Initiated	Status	Reference
Thais clavigera Japanese oyster drill	British Columbia, Canada	1951	Successful	Carlton 2001
Spartina anglica hybrid cordgrass	Ireland	1960s	Unsuccessful; reverted to control	Hammond and Cooper 2002
Macrocystis pyrifera Giant kelp	Hawaii, USA	1972, 1980s	Successful	Shluker 2003
Sargassum muticum Wireweed	England	1973, 1976	Unsuccessful	Carlton 2001
Avicennia marina black mangrove	California, USA	1980	Completed 2000; reappeared 2006	Kay et al. 2006
Spartina alterniflora, S. anglica, and hybrids cordgrasses	New Zealand	1987	Successful in Southland; ongoing elsewhere	http://www.biodiversity.govt.nz/news/media/current/05nov04.html (accessed 14 December 2007) Krikwoken and Hedge 2000
Spartina alterniflora, S. patens, and hybrids cordgrasses	Oregon,	1990	Completed one site; ongoing	Pfauth et al. 2003
	Washington,	2003		Murphy et al. 2007
	California, U.S	2005		Olofson et al. 2007
Asterias amurensis Northern Pacific seastar	Victoria, Australia	1993 2002	Unsuccessful in Port Phillip Bay; near completion at Inverloch	Dommisse and Hough 2004
Perna canaliculus green lipped mussel	South Australia	1996	Successful	Bax and McEnnulty 2001
Terebrasabella heterouncinata sabellid parasite of abalone	California, USA	1996	Successful	Culver and Kuris 2000
Undaria pinnatifida wakame seaweed	Tasmania, Australia	1997	Ongoing	Hewitt et al. 2005
	Catham Islands, New Zealand	2001	Successful	Wotton et al. 2004
	California, USA	2002	Unsuccessful; reverted to control	Lonhart 2003
Mytilopsis sallei black-striped mussel	Northern Territory, Australia	1999	Successful	Bax et al. 2001
Caulerpa taxifolia 'killer' algae	California, USA	2000	Successful	Authors
Ascophyllum nodosum Atlantic rockweed	California, USA	2002	Successful	Miller et al. 2004
Didemnum vexillum colonial sea squirt	New Zealand	2003	Unsuccessful in some areas; ongoing	Coutts and Forrest 2007
Zostera japonica Japanese eelgrass	California, USA	2003	Ongoing	Eicher 2006
Littorina littorea periwinkle snail	California, USA	2005	Near completion	Chang et al. *personal communication*
Batillaria attramentaria horn snail	California, USA	2006	Ongoing at 2 sites	Weiskel and Zabin *personal communication*
Carcinus maenas European green crab	California, USA	2006	Ongoing	Grosholz et al. *unpublished*

Examples of Eradication Attempts in Marine/Estuarine Systems

Costs of Successful Eradication

Examples of successful eradication in coastal systems

Species	Site
Black Striped Mussel	Australia (NT)
Caulerpa	California (SD, OR)
Abalone parasite	California (MB)
NE seaweed	California (SF)



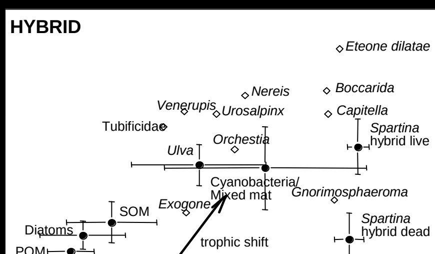
Spartina Invasion

Spartina alterniflora was introduced in 1970s by A.C.E.
Hybridized with native *S. foliosa* and spread throughout central and south SF Bay
Eradication began slowly in 2005, eradication could occur within five years (?)

Impacts of *Spartina* Invasion

Migratory Shorebirds

Resident Canada Geese



Food Web Structure

Other Invasions

Invertebrate Communities

Sediment Biogeochemistry

System Metabolism

Spartina Eradication

Significant Role for Science

- The eradication program both depended on and incorporated input from scientists
- Treatment alternatives (herbicides, mechanical methods, etc.) were tested and compared
- Genetic analysis was key to understanding extent of invasion
- Impacts of invasion were measured concurrently
- Scientific objectives were incorporated into eradication procedures

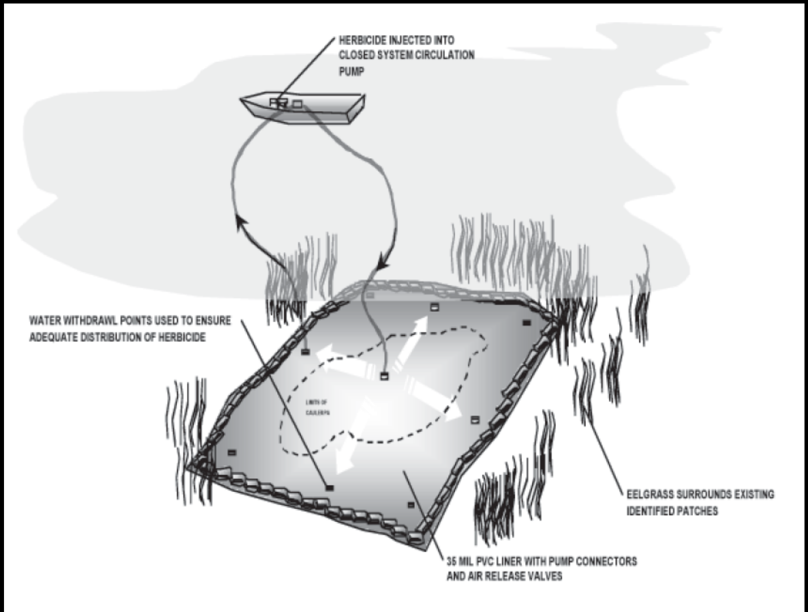
Caulerpa Invasion

Snug Harbor (part of Agua Hedionda Lagoon) overview. Bright green patches are areas of *Caulerpa taxifolia*. *Photo by Merkel and Associates.*

Transect lines swum by divers at Snug Harbor in Agua Hedionda Lagoon to survey for *Caulerpa taxifolia*. *Photo by Merkel and Associates.*

First found at two southern CA sites, Aqua Hedionda and Huntington Harbor in 2000
All *Caulerpa* removed by 2002
Declared eradicated July 2006

Caulerpa Eradication



Diver preparing to inject chlorine under a tarped patch of *Caulerpa taxifolia*. *Photo by Merkel and Associates.*

Chlorine pucks being placed on *Caulerpa taxifolia* before a black containment tarp was placed over the area. *Photo by Merkel and Associates.*

Limited Role for Science

- Eradication methods were undertaken with little validation of effectiveness
- Access to invasion sites was very limited
- Assessment of science needs occurred after the fact
- Still very few quantitative data regarding impacts of *Caulerpa*
- Other eradication methods are untested

Manager’s Perspectives on Scientific Contribution to Eradication

- **What was useful to eradication management?**
  - Access to ecological information
  - Access to previous management programs
  - Risk assessments, particularly spread and control efficacy
  - Identification of introduction and taxonomic ID
  - Studies of control strategies for local conditions
  - Monitoring, including ecosystem function
  - Articulate media communications
  - Vector analysis

Manager's Perspectives on Scientific Contribution to Eradication

- **What other information from scientists would be useful?**
  - Research relevant to invaded range (long-term effects, restoration possibilities)
  - Easier access to data bases (treatment strategies, bibliographic, experts)
  - Coordinated surveys and mapping
  - Earlier results
  - Early definition of roles for scientists and managers
  - Improved certainty of data
  - Better information on invasion threat
  - Cost-benefit analysis

Comparison of Research Needs in Terrestrial and Marine Systems

- Comparably little has been written about the research needs regarding invasive species in marine/estuarine systems
- Compare this with much more coordinated efforts with terrestrial plants
  - CA Noxious and Invasive Weed Action Plan (2005, CDFA and CALIWAC)
- Similar efforts led by the UC was not successful
- Compare the similarities and differences

Comparison of Research Needs in Terrestrial and Marine Systems

- **Similarities**
  - Basic biology and ecology, assement of range of impacts
  - Control and management options
  - Economic costs relative to impacts of invaders
  - Developing effective communication strategies and convey need for eradication/control
  - Methods for early detection and rapid response
  - Integrate science into policy development

Comparison of Research Needs in Terrestrial and Marine Systems

- **Differences**
  - Biological control is currently NOT an option
  - Modeling approaches to predict spread
  - Identification of resistant habitats
  - Identification of impact thresholds
  - Ecosystem impacts of different control/eradication methods
  - Alternative plants to replace invasive ones for sale
  - Effective pre- and postborder screening methods

Some Differences Between Systems

- Options for eradication and control are more limited
  - Biological control is not currently acceptable
  - NPDES permitting greatly limits use of chemicals for eradication and control
- Vectors for spread are less well understood
  - Ships (ballast water, hull fouling) are not well quantified
  - Most marine/estuarine plants are not for sale, although movement of commerical products (e.g. shellfish) may result in spread
- Species almost exclusively non-commercial
  - Very few species for sale (*Caulerpa* rare example)
  - Dispersal and spread not related to intention planting
- Connectivity among populations is poorly understood
  - Are bays and estuaries sufficiently isolated to pursue eradication?
  - Will eradication be effective at the leading edge of an invasion?

A New Agenda for Management Focused Research

- Community and ecosystem impacts of ecosystem engineers
  - Identifying the most important impacts
- Trait-based approaches for prevention
  - Screening targeted species
- Early detection
  - Genetic dip sticks, shotgun sequencing for screening water column

A New Agenda for Management Focused Research

- Evolutionary potential
  - Rapid evolution, changing invaders
- Ecological economics models
  - Incorporating non-market impacts
- Decision support
  - Delivery of information about management methods, species biology, etc.

A New Agenda for Management Focused Research

- Climate change impacts
  - Increased temperature, increased CO_2 and ocean acification
- New methods for eradication and control
  - Biological control, transgenics approaches, pheromonal control
- Understanding connectivity
  - Prioritize control methods

Conceptual Model to Guide Eradication Decisions

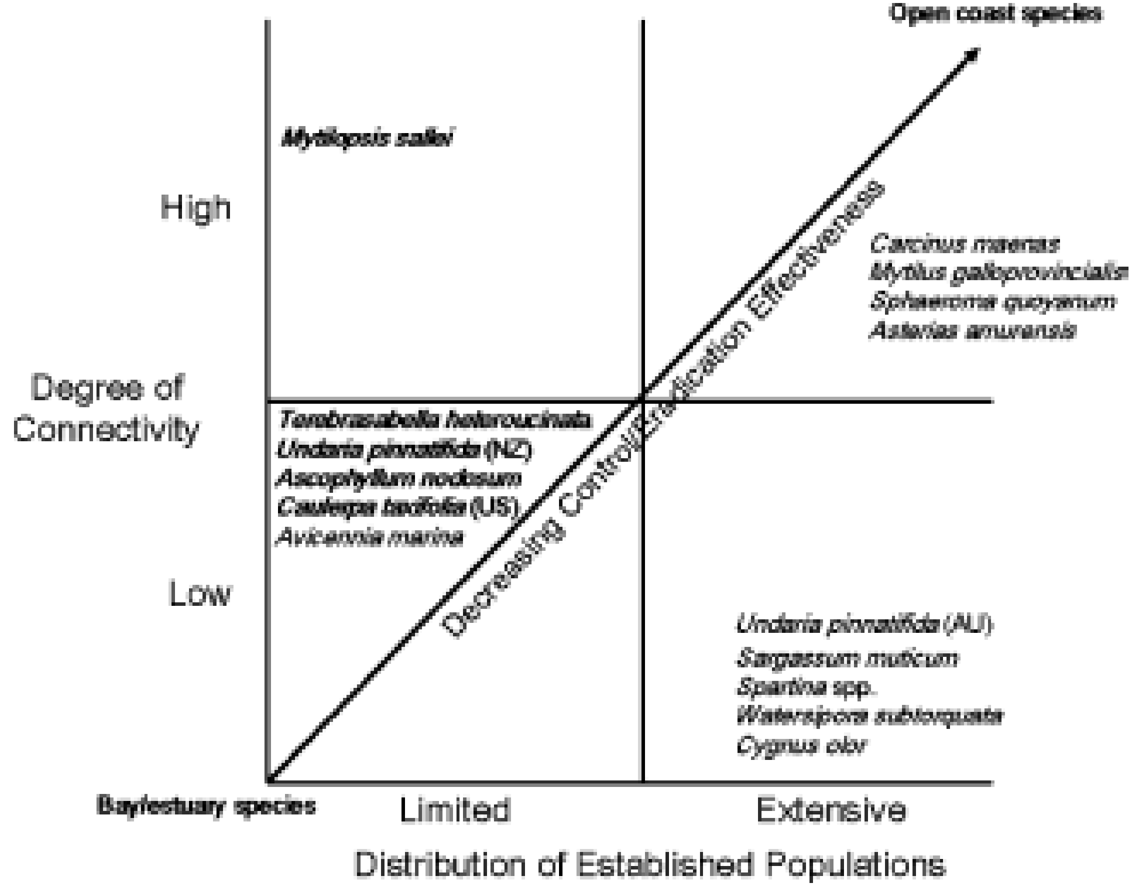


Fig. 4 Conceptual relationship between connectivity (natural dispersal) and expanse of populations of introduced species and the probability of successful management. Species in bold have been successfully eradicated

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