



# Marine Bioinvasions

## THIRD INTERNATIONAL CONFERENCE ON MARINE BIOINVASIONS

March 16-19, 2003

Convened at Scripps Institution of Oceanography, La Jolla, California

**ABSTRACT BOOK**

Sponsored by the California Sea Grant College System and the MIT Sea Grant College Program





International Conference On

# Marine Bioinvasions

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March 16, 2003

Dear Conference Participant:

On behalf of California Sea Grant and MIT Sea Grant, we extend a warm welcome to the Third International Conference on Marine Bioinvasions. We believe you will find the conference program most stimulating and your attendance at this conference most worthwhile. Of the many benefits that you will receive from attending this meeting, we hope that you will develop a greater awareness of the recent progress that has been made and the challenges we still face with marine and coastal invasions.

Once again, welcome to the Third International Conference on Marine Bioinvasions and our best wishes for a stimulating and rewarding experience.

Conference Co-Chairs:

Judith Pederson  
Massachusetts Institute of Technology Sea Grant

Russell Moll  
California Sea Grant

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## CALIFORNIA'S REACTION TO *CAULERPA TAXIFOLIA*: A MODEL FOR INVASIVE SPECIES RAPID RESPONSE ACTIONS

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### Oral Presentation

10:00 AM, Monday

Federal and state agencies are developing plans to prevent introductions of invasive species. These usually include a “Rapid Response”, though details tend to be scarce. California’s very effective reaction to the discovery of the marine alga, *Caulerpa taxifolia*, is an instructive model for rapid response strategies. Within a few weeks following the June 12, 2000 discovery of *C. taxifolia* in Agua Hedionda lagoon near Carlsbad, California, an ad hoc coalition of state, federal, local agencies, private entities and interested stakeholders formed the Southern California Caulerpa Action Team (SCCAT). Containment and chemical treatments began June 29th. Plants were sealed beneath PVC tarps into which liquid chlorine was injected. Later, solid chlorine tablets were used. (Limited surveys and monitoring have so far not revealed any open-coast populations.) SCCAT facilitated an effective, proactive campaign resulting in State legislation to ban *C. taxifolia* and eight other species in September, 2001. Discovery of *C. taxifolia* at Huntington Harbour, SCCAT reacted quickly, using tarping methods appropriate to that site. To streamline functions, a “Steering Committee” was formed, which includes representatives from California Dept. of Food and Agriculture, California Dept. of Fish and Game, San Diego Regional Water Quality Control Board, US Dept. of Agriculture-Agricultural Research Service, and the National Marine Fisheries Service. Several key processes and related decisions made this “rapid response” successful: (1) Quick confirmation of species identity; (2) Immediate communication to appropriate agencies; (3) Immediate access to data on impacts, past history elsewhere; (4) Access to expertise on the biology of *C. taxifolia* and eradication of aquatic plants; (5) Early consensus to eradicate (not “manage”); (6) Solution to regulatory issues; (7) Field crew in place; (8) Access to funds and other resources sufficient to act quickly; and (9) Evaluation of efficacy. SCCAT’s experience reveals what works and what is essential to thwarting similar invasions.

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## INVASIVE GREEN MUSSELS, *PERNA VIRIDIS*, ON MANGROVES AND OYSTER REEFS IN FLORIDA

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### Oral Presentation

8:30 AM, Tuesday

Green mussels, *Perna viridis*, invaded Tampa Bay, Florida, prior to 1999. Initial observations suggested that a biological invasion on the scope of zebra mussels in the Great Lakes was underway. Ongoing studies reveal a more complicated picture. Prior to 2002, green mussels were mostly limited to artificial substrata, including bridge piers, navigational aids, and water intakes. Mats of green mussels also occurred on sediments within a few meters of such structures. Qualitative data indicated that oyster reefs (*Crassostrea virginica*) were only lightly infested, and most of the oysters were alive. Red mangroves (*Rhizophora mangle*), were heavily fouled by other species, including native oysters, mussels, and barnacles, and introduced barnacles (*Balanus amphitrite*), but lacked green mussels. There was hope that the green mussel would remain essentially urban in its habitat.

Surveys in 2002 revealed that the green mussels occupy more habitats, through continued recruitment and spread. In particular, green mussels have become far more abundant on eastern oyster reefs than previously noted. Densities are very high, and green mussels replace the biomass formerly produced by oysters. The oyster reef matrix and structure remain, but over 90% of adult oysters are recently dead (shells still articulated by the ligament). Other species, including native barnacles and mussels, have not been displaced, and occur in densities comparable to uninvaded reefs outside Tampa Bay. This finding is correlative only, and does not demonstrate cause and effect. Oyster reefs dominated by crested oysters (*Ostrea equestris*) are invaded by green mussels, but only at low densities so far. In contrast to oyster reefs, red mangroves remain almost entirely free of green mussels, and thus remain a refuge for native oysters. These findings were unexpected, based on the literature, and illustrate the difficulty in predicting impacts of nonindigenous species.

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## MOLECULAR SYSTEMATICS OF THE INVASIVE CTENOPHORE, *MNEMIOPSIS* SP.

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### Poster Presentation

Tuesday

The ctenophore genus *Mnemiopsis* currently contains two species (*M. leidyi* and *M. mccradyi*), with native ranges from Massachusetts to Southern Argentina. Over the past 20 years, these ctenophores have been introduced to the Black, Azov and Caspian Seas. In order to clarify the taxonomy and population genetics of *Mnemiopsis*, we have collected nuclear and mitochondrial sequence data from representatives of both putative species. The nuclear internal transcribed spacer regions (ITS) 1 and 2 were sequenced from 63 individuals collected from 22 different geographic regions spanning the ctenophores' native and invaded ranges. We found no length variation in ITS-1 (233 bp) or ITS2 (228 bp). Furthermore, percent sequence divergence was low (0-0.9% for both ITS1 and ITS2) and within the range of intra-specific divergence found in other organisms, suggesting the presence of only one species of *Mnemiopsis* in all geographic ranges. Geographic analysis of ITS1/ITS2 composite genotypes indicates that South American *Mnemiopsis* (Argentina and Brazil) are isolated from North American populations (Atlantic/Gulf of Mexico coasts) and a weak population break exists around Cape Hatteras in North American waters. All invasive *Mnemiopsis* share genotypes with North American ctenophores, with the largest overlap occurring between invasive ctenophores and those south of Cape Hatteras into the Gulf of Mexico. Results from ongoing studies of additional nuclear and mitochondrial markers will also be presented.

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## FLUCTUATIONS OF ZOOPLANKTON ASSEMBLAGES DURING MID-OCEAN EXCHANGE OF BALLAST WATER

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### Poster Presentation

Monday

As a recommended but voluntary measure, ballast water is exchanged in mid-ocean (BWE) with the hope to reduce introductions of exotic species. This investigation of BWE efficiency was carried out on a 26 day voyage of C/V Pusan Senator en-route from Asia to Europe in the Indian Ocean (in the evening) and in the Bay of Biscay (in the morning) in May/June 1999. Both BWE experiments were undertaken at normal cruising speed (23-24 knots) and in both instances the identical ballast tank was emptied and refilled 3 times. Zooplankton samples were taken using 3 different plankton nets before, during and after each BWE. Ballast water that was discharged in the Indian Ocean was 6 days old, originated from Singapore and contained on average 2 taxa and 10 individuals per 10 liters at discharge. The number of taxa and individuals increased during the BWE and 12 hours after the third ballast water refill was completed the average number of taxa was 2.6 with an average number of individuals of 27 per 10 liters. Ballast water that was discharged in the Bay of Biscay was 6 days old, originated from the roads of Suez and contained on average 4 taxa and 462 individuals per 10 liters. Two hours after the third ballast water refill the number of taxa and individuals decreased to 1.9 taxa and 90 individuals per 10 litres. The efficiency of BWE to reduce the risk of future species introductions is discussed.

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## NONINDIGENOUS MARINE SPECIES IN HUMBOLDT BAY, CALIFORNIA

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### Oral Presentation

1:30 PM, Wednesday

During 2001 and 2002, 95 species with a high probability of being nonindigenous marine species were collected from Humboldt Bay. Species from most major groups of organisms were taken, ranging from vascular plants to fish. The largest number of species were from various invertebrate groups, including polychaetes (24 species), amphipods (20 species), and bryozoa (8 species). Previous studies in Humboldt Bay had identified 31 nonindigenous species that were reacquired in this survey.

Several introduced species have been in Humboldt Bay for a long time, in some cases going back to the first settlement of the region by Europeans in the 1850's. The most abundant plant of Humboldt Bay salt marshes was brought into the bay from South America, probably as shingle or dry ballast. Intentional introductions have also accounted for a number of species that are numerous in the bay. Japanese oysters were successfully introduced into Humboldt Bay in the 1930's. A significant commercial aquaculture activity continues around the planting, growth, and harvesting of Japanese oysters in the bay. One species of algae previously unreported from Humboldt Bay probably arrived in oyster cultch from Puget Sound. Other examples of species introduced intentionally include the Eastern soft shell clam and the Japanese cockle. Included in this study were species that are clearly the result of introductions and those that have been characterized as cryptogenic. Of the 95 species identified as possible introductions to Humboldt Bay, 11 are probably cryptogenic, and an additional 13 species may be cryptogenic.

The occurrence of nonindigenous species in Humboldt Bay was compared to their occurrence in San Francisco Bay to the south and in Coos Bay, Oregon to the north. Of the 95 species in Humboldt Bay, 31 have been reported from all three bays. Co-occurrence records suggest that San Francisco Bay is an important source area for introductions to Humboldt Bay, a finding consistent with ship and small boat traffic moving between these two locations. The number of species that appear to be found only in Humboldt Bay (27) suggests that there may be factors in the nature of shipping or other human influences that are unique to the bay.

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## CONTEXT-DEPENDENT IMPACTS OF MULTIPLE INVASIVE SPECIES ON A THREATENED NATIVE SPECIES IN A WEST COAST ESTUARY

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### Oral Presentation

10:45 AM, Monday

Despite recent efforts to develop consistent methods of quantifying the ecological impacts of invasive species, many challenges remain. One difficulty is that the impact of a given invader may depend on ecological context, so small-scale measurements may not be representative of impacts throughout the invader's range. To address this issue, it may be useful to identify factors, such as habitat attributes or resident community composition, that drive variation in an invader's density or per capita effect. We are investigating such factors in the impacts of two invasive oyster drills, *Ceratostoma inornatum* and *Urosalpinx cinerea*, and the introduced oyster, *Crassostrea gigas*, on the threatened native oyster, *Ostreola conchaphila* in Willapa Bay, Washington. High drill densities are associated with *C. gigas* reefs and aquaculture beds. In addition, observations of damage to drill shells and results from a tethering experiment indicate that predation by native cancrid crabs may significantly influence drill distribution and density. Drills preferentially select *C. gigas* when presented with both oyster species in feeding trials, suggesting that predation impacts on native oysters may depend on the relative abundance of alternative prey. An enclosure experiment designed to test direct and indirect interactions among *C. inornatum* and the two oyster species found that predation rates on *O. conchaphila* decrease with increasing abundance of *C. gigas*, though the effect is statistically nonsignificant. This effect was not detectable in field measurements of *O. conchaphila* mortality rates across community types. Our results to date suggest several mechanisms whereby physical habitat factors, native community composition, and interactions among invasive species could modify both the abundance and per capita impact of invaders. More work will be needed to quantify the relative importance of these mechanisms.

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## NOAA'S NICHE IN INVASIVE SPECIES RESEARCH

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### **Oral Presentation**

10:45 AM, Wednesday

The National Oceanic and Atmospheric Administration (NOAA) is one of the steward for this country's oceanic, coastal and Great Lakes natural resources. NOAA's mandate to protect coral reefs, marine sanctuaries, endangered species, fishery, aquaculture, and other resources extends to protection from invasive species threats. Invasive species research conducted in NOAA laboratories or supported by NOAA programs continues to figure significantly in the protection of these resources.

The talk will describe some of NOAA's research programs that address invasive species, and will discuss the various mandates which direct the course of these programs, including the Sea Grant Act, the National Invasive Species Act, and the National Invasive Species Management Plan.

The talk will outline ways that NOAA is working to assure that invasive species research is responsive to state, regional, and national invasive species research needs and priorities. Topics will include the Sea Grant Aquatic Nuisance Species Research and Outreach Program, NOAA's roles on the Aquatic Nuisance Species Task Force, its regional panels, and its newly-formed Research Committee. Coordination and planning of invasive species programs between the Offices of NOAA Research, NOAA Fisheries, and the National Ocean Service, and the relationship of research programs to other NOAA programs that deal with invasive species will also be discussed.

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## CONCEPTUAL MODEL OF BALLAST WATER RISK-REDUCTION

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### Oral Presentation

3:00 PM, Wednesday

The environmental, economic and human health impacts of nonindigenous species introductions via ballast water are important problems that must be addressed not only by scientists, but also by policy analysts. Current policy proposals primarily advocate one global standard for ships. Single-solution, one-size-fits-all efforts, however, ignore that risk varies by port (and trade route) and are therefore likely to be inefficient. Even if regulators first set uniform standards, research is needed to develop models that move beyond first generation “solutions.”

We develop a risk-based approach to characterize factors influencing ballast-water species introductions. Our risk assessment includes the type, number and origin of vessels calling on a port and environmental factors (e.g., salinity and temperature). The model will incorporate current biological understanding as well as permit the synthesis of future insights. Our goal is to produce a model of potential risk-reduction rather than a descriptive biological model. We utilize biological data to perform an advanced synthesis in conjunction with port, technology, and vessel data to determine the risk-reduction potential of various policy options. It will address not only transoceanic shipping as previous research has, but also will evaluate the risk faced by ports from coastwise and regional port to port introductions.

We chose sample ports systems to be representative of geographic location, vessel type and cargo volume so that the model can be applied to ports in all U.S. regions. We apply the model to evaluate how emerging policy can be more successful in preventing ballast water introductions and to generate policy and technology choices that will assist ports in their efforts to prevent such introductions. At this conference, we will present the conceptual framework for the model and provide an update on the current status of the research, including a discussion of our efforts to date at the Port of Houston.

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## WEST COAST BALLAST OUTREACH PROJECT

<http://ballast-outreach-ucsgep.ucdavis.edu>

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### Poster Presentation

Tuesday

Ballast water discharge is recognized as an important pathway for introduction of nonindigenous species throughout the world. In the United States, in recent years, a number of legal, regulatory, and legislative changes have been implemented to improve ballast management and minimize threats from invasive species. In February 1999, the University of California Sea Grant Extension Program initiated a multi-year effort to provide outreach to the shipping industry, government agencies, and the general public about ANS and ballast management issues relevant to the United States West Coast and Pacific Region. The main objectives of the project are:

- 1) to provide education and information exchange on ANS and ballast management issues for the maritime industry, resource agencies, and the general public;
- 2) to provide outreach to the maritime industry on ballast management practices and technologies, and to facilitate improved cooperation and communication and cooperation between the maritime industry, regulators, and researchers concerned with ballast water management, and;
- 3) to facilitate industry interest and participation in the development of ballast management techniques or technologies.

Specific outcomes of this outreach effort include “Stop Ballast Water Invasions”, an appealing, graphics-oriented waterproof poster distributed to ships worldwide via project cooperators, a biannual newsletter “ballast exchange” with a current mailing list of 2000 nationwide and international recipients, and coordination/sponsorship of a number of educational workshops focused on specific ballast management topics. This poster presentation will provide examples of these and other outreach activities which have been developed and implemented through this project to-date. We will also provide information on audience response, evaluation, and participation in various program components.

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## **MARINE BIOINVASIONS AND THEIR IMPACTS ON HABITAT RESTORATION PROJECTS— PERSPECTIVES FOR MANAGERS**

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### **Oral Presentation**

3:45 PM, Monday

Marine bioinvasions can pose significant threats to the success of marine fisheries habitat restoration projects undertaken by the National Marine Fisheries Service in the state of California. In addition to careful planning to prevent accidental introductions, monitoring protocols must be followed and sometimes aggressive measures taken to ensure that project goals are met. The presenter will present two case studies— one in the San Francisco Bay and the other in Southern California, and how invasive species control is being factored into project planning and implementation. The presenter will also note other important considerations in managing the threat of marine bioinvasions— shipping industry and public awareness and action, and approaches regulatory agencies are taking to combat the problem.

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## DIFFERING RESPONSES OF NATIVE AND EXOTIC SPECIES TO INCREASING POLLUTION IN AN ESTUARINE FOULING COMMUNITY

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### Oral Presentation

8:45 AM, Tuesday

Identifying the factors that contribute to the invasibility of communities remains one of the key questions in invasion biology. The preponderance of invaders in areas such as vacant lots and roadsides suggests that stressors such as disturbance and pollution increase invader representation within communities. However, there have been relatively few manipulative experiments that directly test this stress-invasibility relationship, and this shortage is especially conspicuous in marine communities. In this presentation we will discuss the results of such an experiment conducted within the heavily invaded waters of San Francisco Bay, California.

We tested whether increasing levels of an anthropogenic stressor, exposure to copper, affected the relative representation of exotic and native species in the invertebrate fouling community. We deployed bare fouling panels off a seawall, removing them monthly and placing them in buckets with varying levels of copper sulfate solution. After seventy-two hours of copper exposure, plates were returned to ambient conditions. The duration of the experiment was twenty-four weeks.

Species representation on plates confirms that the San Francisco Bay system is heavily invaded. Although similar numbers of native and exotic species were encountered on a per plate basis, exotics overwhelmingly dominated the occupation of space. The average number of native species on a plate declined significantly with increasing copper exposure, while exotic species did not. This supports the hypothesis that increasing pollution levels disproportionately affect natives, and suggests that anthropogenic stressors may be contributing to an increased invasibility of ecosystems.

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## DISTRIBUTION PATTERN OF *CODIUM FRAGILE* POPULATIONS IN ITS NATIVE HABITAT: IS IT SIMILAR TO INVADDED HABITATS?

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### Poster Presentation

Monday

An Asian green alga *Codium Fragile* ssp. *Tomentosoides* native to Japan and Korea, has been established itself as a persist member of coastal communities in several places in Europe and North America. In this study, distribution of *C. fragile* populations was investigated in its native habitat (Korea). Field surveys using quadrats and photographic records were conducted at two study sites: Cheju Island and Tongyong to estimate the densities of canopy species and percent coverage of understory species in the areas. The results showed that at Cheju Island, which is a reserved area, *C. fragile* occurred at 9 m depth and below and can be found as deep as 22 m while *C. minus*, *C. adhaerens*, and *C. cylindricum* were at shallower depths. However, the dominant species were *Ecklonia cava*, *Sargassum filicinum*, and *S. serratifolium*. In Tongyong where several species of algae and marine invertebrates have been overexploited, *C. fragile* and *Ulva pertusa* were the dominant species, covering approximately 90% of the area at all depths, and less than 10% of the remaining area was covered with red algae. *C. fragile* was also found as a major fouling organism around floating docks and port areas. The distribution pattern of *C. fragile* in its native habitats may be an example of how community disturbance and vacant niche may facilitate the spreading of particular species in both their native and invaded habitats.

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## ZOOPLANKTON ARRIVING IN THE SAN FRANCISCO ESTUARY IN THE BALLAST WATER OF CONTAINER SHIPS

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### Poster Presentation

Monday

The record of the introduction of non-native zooplankton species into the San Francisco Estuary dates back to the past century. Container ships are considered partly responsible for the introduction because more voyages are taken by this type than by other types of vessel. The purposes of this study were first to investigate the types and the abundance of zooplankton carried in ballast water of container ships, and second to compare two methods of sampling zooplankton in ballast water: net tows and light traps. We sampled ballast tanks of 20 container ships at the Port of Oakland in July 2002. All of the sampled ships had exchanged ballast water in mid-ocean before entering the bay, as required by California state law. Salinity determined from water samples was over 30, generally confirming the oceanic exchange of ballast water. Despite the exchange processes, we found various taxa of regional and cosmopolitan zooplankton (nil to >100 zooplankton m<sup>-3</sup>) in the samples, including species previously reported to have invaded the bay. There was little difference in the number of zooplankton taxa found in the samples taken by net tow vs. those taken by light trap, but a noticeable difference in the relative abundance of taxa, suggesting some taxa may have been selectively attracted by light. The zooplankton data also suggest that some zooplankton may have been taken in from the ocean during the exchange process. The presence of many nauplii in the samples suggests that hydrographic condition in the tanks were not hostile for the reproduction of the zooplankton. Experiments are ongoing to address the subsequent questions of what factors may have caused the large variation of the zooplankton abundance among vessels and as to whether the exchange process may be an additional source of zooplankton that could potentially be transported to other estuarine ecosystems.

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## EXOTIC ORGANISMS IN SOUTHERN CALIFORNIA BAYS AND HARBORS

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### Oral Presentation

1:15 PM, Wednesday

In recent decades, the world has witnessed an array of harmful invasions by exotic marine organisms. To provide the public and policymakers with better information on the status of exotic species in Southern California waters, the California Department of Fish and Game and the California State Water Resources Control Board, with supplemental funding from the National Fish and Wildlife Foundation, commissioned a Rapid Assessment Survey of selected sheltered waters between San Diego and Oxnard in the summer of 2000. The primary objective of the survey was to assess the status of exotic invasions within certain habitat types in the region. Secondary objectives included obtaining data for comparisons between habitats and regions and for comparisons with past surveys; obtaining baseline data for future assessments of changes in invasion status and the effectiveness of prevention or control efforts; detecting new invasions and documenting significant range extensions; and identifying new species. Twenty-two primary sampling sites and three secondary sites were selected to represent the three major commercial port areas in southern California, important marina areas and lagoon sites. Sampling was primarily of dock fouling along with adjacent soft-bottom benthos, nearby intertidal sites, and selected subtidal lagoon habitats, using a variety of manual techniques. Sixty-seven of the species collected were identified as exotic, with an average of 16.7 exotic species collected at each site. These included representatives from two algal divisions and seven invertebrate phyla. Ascidians were especially well-represented (15 exotic species) and widely occurring, and certain polychaetes, bivalves, isopods and amphipods also occurred widely.

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## DEVELOPING A RESEARCH-BASED MANAGEMENT PROTOCOL FOR THE INVASIVE ALIEN ALGA, *KAPPAPHYCUS ALVAREZII*, IN HAWAII

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### Oral Presentation

10:00 AM, Tuesday

The alien alga, *Kappaphycus alvarezii*, was introduced to one isolated coral reef in the southern portion of Kaneohe Bay, Hawaii in 1974 and has subsequently spread at approximately 260m/yr to coral patch reefs throughout the bay. *K. alvarezii* presents a serious danger to the reefs within the bay. Permanent photoquadrats have established the ability of this alga to overgrow and kill corals, while benthic surveys have shown that the alga has already overgrown >50% of the reef substrate in some areas. Because of the destructive nature of this alga and its continued spread throughout the bay, the development of an efficient and effective management plan for this species is imperative. Manual removal of algae in plots has been initiated but rapid regrowth has occurred in some cases. The goal of this study was to investigate ecological factors that may influence the re-establishment of this invasive species, specifically addressing the roles of herbivory and nutrient levels. A factorial experiment was conducted comparing the impacts of nutrient addition, herbivorous fish exclusion, and urchin addition on the rate at which *K. alvarezii* re-establishes. Urchin additions utilized the native sea urchin, *Tripneustes gratilla*, as a means of enhancing herbivory. Results demonstrate that, 1) algae will regrow in plots unless further action is taken, 2) increases in nutrient availability lead to increased rates of regrowth, and 3) the enhancement of herbivore densities dramatically decreased the rate at which regrowth occurred. The results obtained with the urchins in the above experiment led to the addition of urchins to plots where *K. alvarezii* cover was approximately 60%. These plots showed that urchins in high densities could reduce invasive algal cover by almost 100% in 2-3 months. Research on the culture and deployment of these urchins as biocontrol agents is currently underway.

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## RECRUITING RECREATIONAL DIVERS TO MONITOR AQUATIC NUISANCE SPECIES (ANS) IN PUGET SOUND

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### Poster Presentation

Monday

Recreational divers have the potential to act as important sentinels in the search for introduced marine and freshwater species. As a group divers are enthusiastic learners about the marine environment and its inhabitants, they are frequent visitors to the water and beaches, and they relish having a task to perform underwater. Divers tend to be well-educated members of the public and are anxious to share their knowledge with family and friends, making them ideal target audiences for spreading the word on the presence and impacts of aquatic nuisance species.

Investigators at the Washington Sea Grant Program (WSGP), recruited recreational divers from the Puget Sound, Washington, area for training in the recognition and reporting of non-native species. Working with the largest local dive publication, Northwest Dive News, and several local area dive organizations, interpretive centers and dive clubs, we held a series of workshops in locations throughout Puget Sound. The workshops introduced divers to the concept of native and non-native species, described the impacts of invasive introductions, and provided them with materials to aid in the identification of ANS. Through videos, color photographs, scientific drawings and preserved materials the divers are lead through the process of recognizing non-native species of concern in the estuary and taught them to distinguish them from similar appearing native species. Divers are provided with printed information and identification guides developed by WSGP including a waterproof card that can be used with the divers' slates underwater.

WSGP created an on-line reporting form to allow divers to log dives in local waters and to report sightings of possible ANS. WSGP staff monitor the reports and alert state Fish and Wildlife officials of sightings so they can follow up the sightings.

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## THE ORIGIN AND CONSEQUENCES OF ZOOPLANKTON ARRIVING IN VANCOUVER, CANADA, AND PUGET SOUND, USA

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### Poster Presentation

Monday

A number of invasive marine and estuarine benthic invertebrates have probably been introduced to the west coasts of Canada and the United States via transport of their larvae in ship's ballast. In addition, at least eight species of Asian planktonic copepods have invaded San Francisco Bay, the Columbia River estuary, and other coastal embayments of the west coast of the United States. However, to date, none of these copepod species has become established in Puget Sound or in Canadian waters. One method that may be useful in assessing the colonization risk of nonindigenous plankton species is determining the life-history stages, species, originating locations, and frequency of occurrence of fauna being brought into these regions. We present data from three studies: (1) five mid-ocean ballast-exchange (MOE) experiments conducted on a single ship transporting ballast between the northwestern Pacific and Vancouver, Canada; (2) enumeration of low and high salinity ballast from sixteen ships entering Vancouver from Asia, California, and several other regions; and (3) species-level enumeration of copepods from eleven ships entering Puget Sound from Asian ports. In the exchange experiments, MOE appeared to be quite effective at decreasing coastal taxa, removing between 84% (harpacticoid copepods) and 100% (several calanoid copepod taxa) of dominant coastal taxa/groups from the ship's ballast. On the other hand, samples from ships entering Vancouver Harbor and Puget Sound had high diversity and abundance and sometimes high percentages of coastal taxa, in both exchanged and unexchanged vessels. According to ecophysiological data from the literature, some of these taxa are potential colonizers of Canadian and northwestern United States waters. High abundances of these organisms in ships that had undergone MOE could indicate either that MOE was ineffective, or that it had been reported but not actually completed.

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## WHAT DO EXOTICS DO TO ECOSYSTEMS?

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### Oral Presentation

1:30 PM, Monday

Invader-induced alterations of ecosystems have a wide variety of cascading effects on resident species, and thus they are among the most important of invader impacts. There have been several efforts to classify such ecosystem-level effects, although these typically lack generality because they derive from work done in terrestrial systems (where animals are never dominant structural elements) and they confound effects on resources with the mechanisms that produce those effects. In order to address this, a new scheme has been developed that recognizes three primary ecosystem-level effects of exotics: the alteration of the flow, availability, or quality of 1) nutrient resources within biogeochemical cycles, 2) trophic resources within food webs, and 3) physical resources such as living space, light, and water. The proximate mechanisms by which these effects can occur include virtually any interaction between one organism and another organism or the physical environment, including predation, competition, herbivory, and ecosystem engineering. The latter, which represents biotic control over habitat structure, is particularly important in relation to the mediation of physical resources. Ecosystem engineers also can indirectly affect nutrient and trophic flows.

Of all the ecosystem-level effects of invaders, physical alteration of ecosystems may prove to have the most predictable outcomes. In general, exotics that increase habitat complexity facilitate resident species, while those that decrease complexity do the reverse (a pattern similar to that found for native species). Although there are many possible explanations for this relationship, behavioral experiments with shrimp demonstrate a very strong correlation between population density and the degree of habitat complexity. This demonstrates that species simply choosing complex habitats over simple ones helps shape biotic responses to invader-altered ecosystems.

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## INVASION LIMITATION BY BIOTIC VERSUS PHYSICAL FACTORS: DOES *CALLINECTES SAPIDUS* LIMIT *CARCINUS MAENAS* POPULATION SIZE AND DISTRIBUTION IN EASTERN NORTH AMERICA?

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### Oral Presentation

9:15 AM, Wednesday

The European green crab, *Carcinus maenas*, is a destructive nonindigenous species common in coastal American waters from Maryland to Nova Scotia and now also from California to British Columbia. Despite the ecological and economic threats posed by this crab, we do not yet know what factors limit its spread and local abundance. This research examines the roles of predation and temperature in limiting the distribution and size of green crab populations in their western Atlantic range. Using multiple field and laboratory measures, we tested whether predation by the native blue crab, *Callinectes sapidus*, can limit *C. maenas* distribution and abundance. Our field-based surveys, using standardized trapping for both crabs, indicate a significant negative correlation in abundance between crab species, across bays from Maine to Virginia: *C. sapidus* declines and *C. maenas* increases in abundance from south to north. A similar negative correlation in abundance is also found within some individual bays. Using tethered green crabs as an index of predation pressure indicates that (a) predation on green crabs increases generally southward and (b) predation is positively correlated with blue crab abundance. In addition, laboratory and field experiments indicate that blue crabs cause significant mortality. These data are consistent with the hypothesis that blue crabs impose limits on the distribution and abundance of green crabs. We are now testing whether temperature, which also increases from north to south, may contribute to the overall pattern across bays.

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## ARE INVASIONS PREDICTABLE? AMERICAN SLIPPER LIMPETS (*CREPIDULA FORNICATA*) AND PACIFIC OYSTERS (*CRASSOSTREA GIGAS*) IN THE NORTHERN WADDEN SEA (NORTH SEA, EUROPE)

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### Oral Presentation

9:00 AM, Wednesday

Oyster culture has a long tradition in the northern Wadden Sea. However, in the early 20th century overexploitation resulted in a dramatic decline of the native oyster population. To compensate for the loss of the European oyster (*Ostrea edulis*) fishermen imported seed oysters from other parts of the world, starting with American oysters (*Crassostrea virginica*). These oysters proved to be not suitable for cultivation in the North Sea and disappeared shortly after their introduction. However, settling on top of the oyster shells, the American slipper limpet (*Crepidula fornicata*) was unintentionally co-introduced. Instead of vanishing following the extinction of their initial oyster substrate, the snail managed to shift from this sublittoral substrate to intertidal native mussel beds (*Mytilus edulis*). Consequently, the species was able to survive and expand into a new habitat due to its flexibility. However, a then predicted population explosion like at other European coasts has not occurred probably because of a high sensitivity to cold winters.

Since the 1960s Pacific oysters (*Crassostrea gigas*) are regularly imported into the North Sea for aquaculture purposes and are now rapidly increasing in abundance and range in their new environment. Even though brought in an area where the native oyster went extinct, the exotic oyster did not move into the vacant niche. As *Crassostrea gigas* is much more viable and competitive than the native oyster was, it can occupy a wider niche and is about to pose problems to the native mussel beds as well as to mussel fisheries.

Based on these two case studies we show that the course of invasions is hardly predictable but shows unexpected turns. This seems to be especially true at local scales.

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## PATHOGENS IN SHIPS' BALLAST WATER AND SEDIMENT RESIDUALS

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### Oral Presentation

11:45 AM, Wednesday

The microbiology of water and sediment within ballast tanks is relatively understudied (with the exception of dinoflagellates), yet there are numerous good reasons to investigate the presence, dynamics, and survival of microorganisms in these environments. Not the least of these reasons concerns the documented (and potential) dispersal of pathogens and their genes via ships' ballasting operations. In the course of research in the Chesapeake Bay and the Great Lakes, we have collected samples of water and sediment residuals from nearly 200 ballast tanks. We report here the rare to occasional presence in these samples of viruses, bacteria, and protists pathogenic (or potentially so) to humans and fish. Using cultural methods or molecular probes, we have found: human or animal enterovirus (agent of gastroenteritis); *Vibrio cholerae* (bacterial cause of human cholera); *Aeromonas* spp. (some species are opportunistic bacterial pathogens of humans or fish); *Cryptosporidium parvum*, *Giardia duodenalis*, and *Encephalitozoon intestinalis* (protozoan parasites of human intestines); *Pfiesteria piscicida* and *P. shumwayae* (dinoflagellates associated with fish kills). We have no evidence that human caliciviruses (PCR-based detection) or enteric bacteria (e.g., *E. coli* and enterococci; culture-based studies) were present in these samples. Although we focus here on water and sediments of ballast tanks, pathogenic organisms also are present in tank biofilms (see abstract by Drake et al.).

We are exploring hypotheses that the presence of pathogens is higher in ships sampled during warmer months or in ships not recently having undertaken open-ocean exchange. We also are investigating whether there is an association between pathogen load and the ships' last ports-of-call. Our evidence to date supports none of these hypotheses. Instead, the occurrence of pathogens is distributed without discernible correlation across ships, last port-of-call, and seasons of the year. We will discuss the management and regulatory ramifications of these results.

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## EFFECTS OF OPEN-OCEAN EXCHANGE ON MICROBIAL COMMUNITIES IN SHIPS' BALLAST TANKS

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### Poster Presentation

Monday

For several years, we have investigated the effects of transoceanic transport and open-ocean exchange on aquatic microbial communities in ballast tanks. Our goals were to assess the performance of exchange as a barrier to future invasions and to collect base-line data with which to compare and evaluate competing treatment technologies. To that end, we have quantified the concentrations of bacteria, virus-like-particles (VLPs), algal pigments (chlorophyll a and phaeopigments), total microbial biomass, and examined changes in microbial species composition and diversity within tanks as a result of transport and exchange. In summer 1999, we rode a coal carrier, Hadera, from Hadera, Israel, to Baltimore, USA (19-day voyage), and performed 149% exchange on Day 10. In the summer of 2002, we conducted another experiment on board an iron-ore carrier, Berge Nord, from Rotterdam, The Netherlands, to Sept Iles, Canada (9-day voyage), during which 300% exchange was performed on Day 3. On both voyages, there was a time-dependent decrease in the abundance of VLPs, bacteria, microbial biomass and algal pigments in tanks prior to exchange, a decrease that continued over time in unexchanged, control tanks. However, exchange affected various components of the microbial community differently, e.g., for the Hadera experiment, VLP abundance decreased, but bacteria abundance, total microbial biomass and chl-a concentrations did not change. For the Berge Nord experiment, VLP abundance decreased following exchange, however bacteria abundance increased. While these bulk parameters may indicate little or inconsistent effects of exchange on the microbial community, our analyses to date show there is a significant change in microbial diversity. Of the various groups of bacteria present in ballast tanks, some appear to dominate in unexchanged tanks, and others are only present in exchanged tanks. We will discuss the operational, managerial, and regulatory considerations of ballast-water exchange in the context of these results.

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## SHIPS' SEA CHESTS: THE OVERLOOKED MECHANISM FOR SPECIES TRANSFERS?

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### Oral Presentation

1:30 PM, Tuesday

Ballast water is commonly thought to be the major mechanism responsible for the dispersal of nonindigenous marine organisms around the world. However, recent studies suggest that hull fouling (both historically and recently) has been responsible for more shipping introductions than ballast water. The possibility that ships' sea chests (ballast water intakes) serve as another major dispersal mechanism for marine organisms has been largely overlooked. Sea chests may well be modern day equivalents of the "galleries" created by shipworms in pre-20th century wooden hulled vessels.

Since 1999, Cawthron Institute, New Zealand, has been undertaking a survey of vessels (<6,000 DWT) slipped and dry docked in three ports to determine the types of organisms being carried in sea chests. Sea chest cavities have been found to provide a haven for a wide range of indigenous and nonindigenous sessile and mobile marine organisms such as amphipods, ascidians, barnacles, bivalves, bryozoans, copepods, decapods, fish, gastropods, hydroids and polychaetes.

In particular, two live nonindigenous crabs, *Charybdis hellerii* and *Pilumnus minutus* (a male and an egg-bearing female) were found in the sea chest of a foreign fishing vessel and the latter species could have survived in Auckland had they escaped there. Such discoveries provide compelling evidence to suggest that sea chests are an important mechanism for the transfer of marine species into New Zealand's coastal waters. In addition to dry dock and slipway inspections, Cawthron Institute and Pacifica Shipping (1985) Limited are investigating methods of preventing the infestation of sea chests, including assessing the efficacy of Cathelco® impressed current cathodic protection systems on three of Pacifica's coastal vessels.

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## THE ROLE OF PORT MONITORING IN MARINE PEST MANAGEMENT FOR AUSTRALIA

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### **Oral Presentation**

2:00 PM, Tuesday

The IMO complete guidelines for the control and management of ships' ballast water now provide clauses that require port States to carry out biological baseline surveys in waters under their jurisdictions and disseminate the results. To date however, approaches to systematically link port monitoring, including port baseline surveys, to environmental policy development and the long-term management of marine pests are in their infancy. As a result the utility of the data arising from port monitoring in terms of policy development, early detection of pests, and the population of risk evaluation models for vector management, have yet to be fully realised. This paper discusses the development of a conceptual model for Australia's marine invasive species management. For consistency, the model has been frame-worked into the ISO 14001 Standard for environmental management. Here, we discuss the role of port monitoring as a feedback tool to inform both ongoing development and review of the pest management model. By linking port monitoring to a structured management model we are able to examine the cost/benefits of port-baseline surveys and ongoing port monitoring in relation to Australia's resources for managing marine invasive species.

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## ENTRAINMENT OF THE NORTH PACIFIC SEASTAR, *ASTERIAS AMURENSIS*, IN NON-BALLAST VECTORS: SHIPS HULLS, AQUACULTURE AND FISHING GEAR

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### Poster Presentation

Tuesday

The Northern Pacific seastar, *Asterias amurensis*, is a voracious predator that threatens 1000's kilometres of Australia's southern waters to a depth of at least 100m. Once established, eradication of the seastar is not practical. Australia has developed a comprehensive National Control Plan to minimise the spread of the seastar and reduce its impacts on Australia's marine biodiversity and industries. This study focuses on identifying the epidemiological characteristics of *A. amurensis* within three broad vector types: ship hulls, fishing gear and aquaculture gear. This data will augment a growing database on the infection rates of *A. amurensis* to various vectors so that potential management interventions can be prioritized. Information for this study has been collected through a desk-based review, expert judgment and targeted surveys. Results to date suggest that fishing gear and aquaculture may be significant vectors for *A. amurensis*. Snapper fishermen in Port Phillip Bay for example, report 100% losses of bait to *A. amurensis* on a single deployment (up to 200 hooks). Tasmanian shellfish farmers routinely report heavy losses of juvenile stock to settling *A. amurensis* that grow up to three times the rate of other (native) predators. In contrast, there have been no *A. amurensis* sightings on vessel hulls, although it is possible that small juveniles, sheltering in heavily fouled areas, may have been overlooked. There have been isolated cases of *A. amurensis* found in areas associated with the hull (e.g. sea chests) but the infrequency of these sightings suggests that such occurrences are rare. The next step is to reference these observations to vector activities, nodes and pathways in southern Australia so that the potential for transporting *A. amurensis* from current sites of infection can be determined. This information will then be used to populate a risk assessment model for determining the most robust means of managing the threat posed by the seastar.

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## AQUATIC NONINDIGENOUS SPECIES IN THE CHANGING LOWER COLUMBIA RIVER ESTUARY, USA

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### Oral Presentation

2:30 PM, Wednesday

The lower Columbia River Estuary is extensively altered by upstream damming and hydroelectric projects, loss of wetlands, reduced freshwater flow oscillations, altered shipping, fishing, and land use practices, by regional climate changes ranging from el Niño events to global warming and by introductions of aquatic nonindigenous species (ANS). Our literature review, and 2002 field sampling indicate that the increasing rate of new introductions, their increasing likely impacts, and the mechanisms bringing these introductions are in common with other eastern Pacific estuaries. However, the relatively high summer freshwater flows of the Columbia River estuary create unique assemblages of introduced species. We did not find some widespread ANS we expected, such as the smooth cordgrass, *Spartina alterniflora*, and the European green crab, *Carcinus maenas*, and we were unable to confirm numerous sightings of the mitten crab *Eriocheir sinensis* in the Columbia River. Large alterations of the estuary discovered in the survey include: the replacement of the previously dominant *Pseudodiaptomus inopinus* by the introduced *Pseudodiaptomus forbesi*, *P. forbesi* is now being dominant, and its range extended north from San Francisco Bay, California; a new and unidentified gammaridean amphipod, *Monoporeia* that appeared in the estuary in the last few years and; extensive, populations of the New Zealand mud snail, *Potamopyrgus antipodarum*.

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## POTENTIAL INVASION OF MICROORGANISMS AND PATHOGENS VIA 'INTERIOR HULL FOULING': BIOFILMS INSIDE BALLAST-WATER TANKS

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### Poster Presentation

Monday

Aquatic nuisance species (ANS) have the potential to effect great ecological and economic change, and a primary vector for global transport of ANS is ballast water discharged from ships. Research on ballast-water introductions has emphasized the role of metazoans, with good reason (e.g., the invasion of the zebra mussel to the North American Great Lakes), yet microorganisms are indisputably the most abundant aquatic organisms, and, therefore, species most likely to be transported in ballast water. While studies of microorganisms in ballast tanks have focused on whole-water samples, scant information exists concerning the biofilms that cover internal tank and hold surfaces.

Surfaces submerged in an aquatic milieu are covered to some degree with biofilms - organic matrices that can contain bacteria, microalgae, and protozoans - that sometimes include disease-causing forms. One unquantified risk of marine invasion is the potential for biofilms within ballast-water tanks and holds to harbor pathogens, and, in turn, seed other waters. In order to evaluate this vector, we are collecting biofilm samples from ballast-water tanks in ships, and we are deploying controlled-surface sampling units within ships' ballast-water tanks. We then quantify a variety of microbial metrics within the biofilms, including the presence of specific pathogens.

Field experiments and sampling showed a number of potential pathogens in biofilms. For example, we detected *Pseudomonas putrefaciens* and *Vibrio alginolyticus*, bacteria that can become pathogenic under certain conditions. We also detected the bacterium *Vibrio cholerae* in biofilms and ballast water, although two subsequent analytical techniques revealed neither of the human-cholera serogroups (O1 and O139). Finally, we recovered dinoflagellate cysts from biofilm samples, and they later germinated to swimming cells. We continue to collect biofilm samples from ships, conduct field experiments, and perform laboratory 'seeding' experiments - these data, which will allow a better estimation of bioinvasive risk, will be discussed.

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## FORAGING BEHAVIOR OF TWO CRAB SPECIES ON NATIVE AND NONINDIGENOUS BIVALVES IN COASTAL BRITISH COLUMBIA

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### Oral Presentation

3:45 PM, Tuesday

Experiments were conducted to determine if two sizes of cancrid crabs (Dungeness crab, *Cancer magister*; red rock crab, *Cancer productus*) prefer native littleneck (*Protothaca* spp.) bivalves to the varnish clam (*Nuttallia obscurata*), a recently introduced species from Japan. Prey preference, handling time and consumption rates were investigated for both clam species. Results showed that cancrid crabs preferred varnish clams over the native species. This may be attributable to the lower handling time the crabs required to consume the varnish clam due to its thinner shell. Handling time appears to be a factor not only in species preference, but also in the degree of preference, with shorter varnish clam handling times corresponding to stronger preference values.

Both native and introduced bivalves burrow into the substrate, with the varnish clam burrowing to greater depths. To investigate burial depth as a refuge from predation, equal numbers of each clam species were allowed to bury in 'limited' (5 cm) and 'unlimited' (15 cm) substrate, before exposure to crab predation. In limited substrate both crab species preferred the varnish clam. In the unlimited substrate trials the Dungeness crabs preferred the varnish clam while the red rock crab showed preference for the native littleneck. This is likely due to the significantly deeper burial of the varnish clam, making it less accessible. These results demonstrate how interactions between native predators and habitat characteristics (e.g. substrate) can be important in determining how successful an invader will be.

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## DETERMINATION OF BALLAST WATER ORIGIN BY ITS SPECTRAL PROPERTIES

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### **Poster Presentation**

Tuesday

Based on preliminary experiments and literature reports Dakota Technologies, Inc. has begun to develop a small, simple to use probe, that can be deployed into ship's ballast tanks to determine if the ballast water is of oceanic or coastal origin. The probe will measure both the salinity and near ultraviolet induced fluorescence of the ballast water. We have collected water samples from numerous ports and coastal areas in the United States and have obtained several oceanic samples. We report here early findings on the ability to use spectral properties to determine if water is of coastal or oceanic origin.

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**INTERACTIONS BETWEEN THE ASIAN SHORE CRAB (*HEMIGRAPSPUS SANGUINEUS*) AND THE COMMON MUD CRAB (*PANOPEUS HERBSTII*):  
LARVAL SUPPLY VS. POST-SETTLEMENT COMPETITION**

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**Poster Presentation**

Tuesday

The Asian shore crab (*Hemigrapsus sanguineus*) is a recent invader of rocky intertidal habitat along the Middle Atlantic and Northeast coasts of the USA. As consequence of this invasion, *H. sanguineus* appears to be displacing native species of crabs. At present the mechanisms by which this displacement is occurring are poorly understood. In this investigation we compared the magnitude of settlement of *H. sanguineus* larvae with that of a co-occurring native crab (*Panopeus herbstii*) in rocky intertidal habitat near the mouth of Delaware Bay (approximately 38.5° N, 75.0° W). Measurements made during the summer of 2001 indicated that settlement of *P. herbstii* larvae was approximately 2 orders of magnitude greater than settlement of *H. sanguineus* during this period. However, collections made at the same location during the autumn of 2001 showed clear numerical dominance of *H. sanguineus* in all post-larval size classes, from the smallest juveniles to mature adults. Thus, we conclude that displacement of *P. herbstii* in this habitat by *H. sanguineus* is not a function of differential larval supply, but rather is related to some aspect of post-larval competition between the 2 species.

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## **EMPLOYING A BACIPS EXPERIMENTAL DESIGN TO EXAMINE THE EFFECTS OF AN INTRODUCED CRAB ON SHOREBIRDS AND THEIR PREY**

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### **Oral Presentation**

4:15 PM, Tuesday

Historically, studies in invasion ecology have focused primarily on the documentation of introductions and their spread. More recently, scientists have been seeking methods to evaluate and predict the effects of invasions on ecosystems, biodiversity, and even on other organisms within a habitat. In this study I applied a rigorous statistical design, Before-After-Control-Intervention-Paired Sampling or BACIPS design, to evaluate the effect of an introduced marine crab on native invertebrates and post-migratory shorebirds. The basic BACI design, without paired sampling, is commonly used in environmental impact studies because it controls for temporal heterogeneity. By pairing samples in addition to the BACI approach one may also control for spatial heterogeneity, which can be an especially confounding factor when working with invertebrates distributed in patches. I will discuss the BACIPS experimental design and novel experimental techniques as I have applied them in a marine system with both invertebrate and vertebrate organisms at risk of impact from an introduced crab.

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## **FISH AS POLLUTANTS: LIMITATIONS OF AND CROSSCURRENTS IN LAW, SCIENCE, MANAGEMENT, AND POLICY**

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### **Oral Presentation**

9:30 AM, Tuesday

When we think of pollutants, we either consciously or unconsciously construct a dichotomy of factors that affect environmental quality and draw a bright line between pollutants and what might be called “natural.” In this dichotomy of thought, a given factor cannot exist on both sides of the divide. That which is natural cannot be a pollutant; that which is a pollutant cannot be natural. Fish are natural and either affect water quality positively or function as a benign barometer of the effects of pollutants, whereas noxious chemicals such as dioxins are pollutants and can only negatively affect water quality. It seems odd to speak of live fish as pollutants, as odd as it would be to speak of dioxins as natural. Nevertheless, the traditional definition of fish as natural may be fading as our awareness increases of how accidental or poorly planned fish introductions can adversely affect the environment. Along these lines, in a lawsuit, a federal magistrate recently found that non-native Atlantic Salmon raised off the coast of Maine that escape from their pens are “pollutants” within the meaning of the Clean Water Act. Because wild Atlantic Salmon is listed as an Endangered Species, Salmon mariculture provides a particularly stark example of when society might aptly consider “fish” that escape to comprise a biointroduced if not a bioinvasive stock, and hence “pollutants.” Drawing on the co-authors backgrounds in law, policy and biology, the paper considers the biological, legal, and philosophical implications of this notion for mariculture as well as for traditional fish stocking and management and the wider concern over marine bioinvasions.

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## **DETERMINING THE RISK POSED BY INTERNATIONAL PLEASURE CRAFT AS A TRANSPORT VECTOR FOR NONINDIGENOUS MARINE SPECIES**

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### **Poster Presentation**

Monday

Fouling on the hulls of private pleasure craft has been implicated as a likely means of transportation of nonindigenous aquatic species in many areas of the world. New Zealand is a popular destination for ocean cruising yachts and other private boats, and is visited by 400 to 500 overseas yachts per year. To estimate the risk that these craft pose to New Zealand's marine biosecurity, the National Institute of Water and Atmospheric Research (NIWA) has commenced a research project that aims to determine: (1) risk factors for the presence and abundance of fouling organisms on the hulls of overseas yachts, and (2) the numbers of boats that are high risk vectors. The identification of risk factors is contingent on obtaining a representative sample of overseas boats. A reporting system was developed that allowed Government quarantine officials to make an assessment of visible fouling on the hulls of vessels arriving from overseas during their routine quarantine clearance of the boat. Inspectors score the fouling visible at the waterline on a rank scale of abundance (from 0 to 5), and obtain details from the owner of the recent travel and hull maintenance history of the boat. In 2002, this information was collected on >70 % (350) of all overseas yachts that entered New Zealand waters. NIWA scientists calibrated the ordinal fouling ranks by sampling the abundance and diversity of different fouling taxa on the hulls of 95 vessels that had recently arrived in the country and were ranked using the scale. This information is currently being used to identify risk factors and to develop predictive models for the presence and abundance of fouling organisms on international boat hulls. Such models will be useful for identifying high risk vessels as they arrive in New Zealand.

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## IN SHIPS OR ON SHIPS? - UNRAVELLING THE RELATIVE CONTRIBUTION OF BALLAST TANKS VS. HULL FOULING TO SHIP-MEDIATED INVASIONS OF NORTH AMERICA BY MARINE SPECIES

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### Oral Presentation

2:45 PM, Tuesday

Since the beginning of navigation, shipping has been a major factor altering the biogeography of marine biota. Historically, estuarine organisms were transported to new coasts on the hulls of ships, in solid ballast, and occasionally in cargo or deck debris. The use of water as ballast, beginning in the late 19th century, led to the global transport of many organisms not adapted to earlier modes of shipping transport. However, the relative importance of different subcomponents of shipping, especially ballast water versus hull fouling to contemporary invasions, is poorly resolved. Using our comprehensive database on estuarine invasions of North America, containing information on life history and invasion history for known nonindigenous species established in our coastal waters, we estimated the contribution of each subcomponent of shipping to invasions for North America. We used details of life history and invasion history of each organism to identify the possible modes of shipping transport, estimating their relative contribution by coast and through time.

Of 316 invertebrate and algal nonindigenous introduced to marine and estuarine waters of North America, we estimated that 163 (52%) were introduced by shipping, and another 88 (28%) included shipping as a possible vector. After 1900, the numbers of newly established nonindigenous attributed to shipping greatly increased, from 25 (pre 1900) to 142 (post 1900). This vast increase reflects, in part, increased scrutiny by marine biologists. Changes in the characteristics of marine nonindigenous, with increasing proportions of mobile species, and species with planktonic larvae, indicate the increasing importance of ballast water as a mode of transport. Importantly, numerous new introductions are sessile organisms, which have short planktonic life-stages, indicating the continuing importance of hull fouling. While ballast water receives well-deserved attention from scientists and policy-makers, it often remains difficult to attribute ship-mediated invasions to either ballast water or hull fouling.

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## COMPARISONS OF DEMOGRAPHIC FEATURES OF AN INVASIVE SPECIES, *OCINEBRELLUS INORNATUS*, VERSUS AN INDIGENOUS SPECIES, *OCENEBRA ERINACEA*

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### Poster Presentation

Tuesday

Because the introduction of foreign species may cause major ecological and socio-economical problems, it is of primary importance to study and monitor the evolutionary processes associated with biological invasions. The timing, patterns, and origin of invasions across multiple species and communities are central themes in invasion ecology. One bridge between the short-term ecological and long term evolutionary aspects of invasion biology is the study of demographic or life history traits, geographical and temporal structure of invasions populations. It has frequently been assumed for example, that successful invasive species will have traits as rapid growth to reproductive age, high offspring production, and potential long distance-dispersal of propagules because life-history features that lead to faster population growth (e.g. fecundity...).

The Asian drill, *Ocenebrellus inornatus* (Recluz, 1851), normally dwells along Sakhalin and Kurile Islands up to Japan and from North of China to Korea. During the 20th century, it was accidentally introduced in two distinct geographic areas. It was first observed along the Pacific coasts of North America: in the Puget Sound (Washington, 1924), in British Columbia (1931), in Oregon (1930-1934) and in California (1941). More recently, its presence was reported on the French Atlantic coast (bay of Marennes-Oléron, 1995). As a predator of native and cultivated mollusks (i.e. oysters, blue mussels, scallops) and because of the presence of a closely related native species (*Ocenebra erinacea*), *O. inornatus* could have important consequences on the regional economy and on species conservation. Studies that examine the biology of invasive species in both their native and introduced range are surprisingly rare, despite the potential insights that can be gained from such comparisons. We thus compare post-establishment range expansion patterns comparing body sizes and patterns of growth of an indigenous (*O. erinacea*) and of an invasive (*O. inornatus*) drilling species and patterns of reproduction and of predation.

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## IDENTIFYING OCEAN REGIONS SUITABLE FOR BALLAST EXCHANGE FOR VESSELS EN ROUTE TO NEW ZEALAND

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### Poster Presentation

Tuesday

Mid-ocean ballast water exchange (BWE) remains the only practical internationally accepted method of reducing the risk of introducing unwanted marine organisms via ballast discharge and is mandatory for all international vessels carrying ballast water destined for discharge in New Zealand (NZ) waters.

The NZ Ministry of Fisheries therefore initiated research aimed at identifying high seas regions suitable for BWE for visiting vessels. The research involved determining the maximum offshore extent of the coastal zone around NZ and off source port locations worldwide. This was achieved by analysing remotely sensed ocean colour and turbidity data via SeaWiFS. Offshore areas outside these coastal zones were deemed to be suitable for BWE, however national, international, legislative and treaty issues must also be taken into consideration before particular areas are delineated.

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## **HULL FOULING AS A PATHWAY FOR MARINE INVASIONS TO HAWAII: AN ANALYSIS OF VECTORS AND DEVELOPING MANAGEMENT STRATEGIES**

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### **Oral Presentation**

2:30 PM, Tuesday

Biological invasions brought about by anthropogenic influences have occurred throughout the world through a variety of mechanisms including maritime shipping, live seafood and bait shipments, aquaculture, shipments of commercial and institutional aquarium species, and the activities of education and research institutions. The primary pathway identified for marine nonindigenous introductions has been maritime vessel traffic to ports around the world through ballast water discharge but there are other pathways associated with maritime vessel activity that can be responsible for introductions.

The Hawaiian Islands are one of the most isolated areas in the world and native plants and animals exist because of pioneering species. In the advent of modern history has created new human-mediated or anthropogenic invasions of alien species through non-native mechanisms. Marine biological invasions brought about by anthropogenic influences have occurred throughout the world. The primary pathway identified for marine alien species introductions has been maritime vessel traffic to ports around the world through ballast water discharge. Maritime vessel activity as a vector for marine alien species is a complex issue involving more than just ballast water. Ocean going vessels can be thought of as “biological islands” for species that dwell in harbors and estuaries. These vessels provide substrate for the settlement of species associated with fouling communities, protected recesses that can be occupied by both sessile and mobile fauna. Recent compilations of marine alien species in Hawaii include some 343 species—287 invertebrates, 24 algae, 20 fish, and 12 flowering plants; of these 212 or 90% are thought to have arrived through hull fouling.

Hull fouling is another pathway associated with maritime vessels that has the potential to transport organisms outside of their native ranges. In the case of ballast water, there have been extensive efforts to document its role as an alien species transport mechanism and create strategies for management. Such efforts have not been focused on hull fouling. Presently, in the state of Hawaii, efforts have begun to analyze the various maritime activities that serve as hull fouling vectors and to create a draft management strategy for dealing with hull fouling, ballast water and ballast sediments.

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## PREDICTING EUROPEAN GREEN CRAB, *CARCINUS MAENAS*, INVASION IN ALASKA

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### Oral Presentation

9:30 AM, Wednesday

*Carcinus maenas* is a euryhaline, coldwater portunid that has invaded multiple locations across the globe. Most recently, in 1989, *C. maenas* was introduced to the California coast and since has spread north to British Columbia and south to Monterey. If it continues its spread north to Alaska, *C. maenas* may have significant impacts on the ecology and economics of the region, based on its predation on commercial and non-commercial invertebrate species, competition for space and habitat disturbance already documented in California. In this study, we examine the environmental constraints to *C. maenas* distribution, exploring whether *C. maenas* larvae can develop successfully in Alaskan waters.

In the laboratory, we measured development rates and survivorship of larvae held at constant temperatures ranging from 10 to 30°C in 30ppt water. Development was also examined in variable temperatures starting at 7.5°C and moving up 2.5°C every 15 days up to 17.5°C. Development times under these conditions, converted to day-degrees, were used to estimate a minimum threshold necessary for larvae to develop successfully to the first juvenile crab stage (C1). This data indicates that development and survivorship is best between 15 and 17.5°C yet larvae were able to develop to C1 stage in temperatures between 10 and 22.5°C. Development rate for larvae raised at variable temperatures fell between those raised in constant temperatures 7.5 and 10°C. This suggests that rate of development may be determined by temperature experienced in the first 30 days of life.

Based on NOS buoy data, at least 4 Alaskan sites have day-degree and salinity conditions above the threshold for development to C1 therefore allowing *C. maenas* to possibly invade Alaska. Using this approach, we will discuss our current work to estimate the potential range of *C. maenas* in North America and elsewhere in the world.

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## STATUS AND IMPACTS OF MARINE ALIEN SPECIES IN SOUTH AFRICA

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### Oral Presentation

12:00 PM, Tuesday

Five marine molluscs have been deliberately introduced into South Africa for aquaculture purposes, while some 18 invertebrates and one seaweed species are known, or suspected, to have been accidentally introduced. Most of these species have either failed to establish naturalised populations, or remain restricted to one or a few harbours and lagoon systems. However, a few - notably the whelk, *Bedevelia paivae*, (East London harbour), the periwinkle, *Littorina saxatilis*, and the anemone, *Sagartia ornata*, (both Langebaan Lagoon) - occur in dense populations in these sites.

Only four introduced species are thought to have significant environmental or economic impacts. The ascidian, *Ciona intestinalis*, is a pest of mussel culture rafts in Saldanha Bay, smothering mussels on the culture ropes. The oyster, *Crassostrea gigas*, has recently established significant wild populations in several southern Cape estuaries, which could be harvested. The European shore crab, *Carcinus maenas*, has spread up to 100 km from its introduction to Cape Town Harbour in about 1983, but remains mainly restricted to sheltered sites. There is concern it may invade the Saldanha Bay system, which contains large areas of ideal habitat, is a centre for mariculture and also a major marine National Park. The Mediterranean mussel, *Mytilus galloprovincialis*, has become the dominant intertidal organism along more than 1 500 km of coastline from Namibia to the Eastern Cape since its introduction in the late 1970's and appears to be continuing to spread eastwards. It outcompetes indigenous mussels and limpets for primary rock space, provides enhanced habitat for infaunal species and has greatly increased the availability of mussels to predators, including both seabirds and humans. Although it has radically altered the appearance and community structure of rocky shores in the region it is not thought to have eliminated any indigenous species. It forms the basis of the South African mariculture industry and the large intertidal stocks also have potential for small-scale commercial exploitation.

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## REDUCING THE RISK OF INTRODUCTION AND DAMAGE OF AQUATIC NONINDIGENOUS SPECIES THROUGH OUTREACH AND EDUCATION

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### **Poster Presentation**

Monday

Introduced non-native species in coastal habitats cost the United States billions of dollars every year. The most effective strategy, either from the point of view of minimizing costs or maximizing ecosystem health is to prevent new introductions. It is this goal, preventing future introductions of aquatic non-native species in California's San Francisco Bay-Delta that is at the heart of the "Reducing the Introduction and Damage of Aquatic Nonindigenous Species" (RIDNIS) project. One part of our project is to facilitate communication and education among industry members, agencies and academia about the current damage by aquatic non-native invasive species in the San Francisco Bay-Delta as well as future risks associated with the importation, sale, and distribution of live exotic plants and animals. Target industries include aquarium and pet dealers, aquatic plant dealers, landscape and "aquascape" contractors, nursery owners, live seafood importers, aquaculturists, live bait dealers and others involved in the importation, sales, and distribution of live plants and animals. These industries deal with numerous non-native species that have the potential to become pest species in the Bay-Delta ecosystem. A second part of our project is to educate the consumers of live plants and animals about the risks posed by introduced aquatic species. To reach consumers we need industry cooperation to distribute educational materials concerning the disposal of unwanted plants or animals. Project outcomes include 1) hosting workshops in the region to gather industry input in the development of new methods to reduce introductions; 2) a full-color brochure highlighting pest species of concern, impacts of these non-native species on native taxa, pathways of dispersal, and methods for preventing dispersal; 3) a video to provide information about the mechanisms of aquatic non-native species introductions as well as management solutions specific to the target industries; and 4) a project website (<http://www.ridnis.ucdavis.edu>) highlighting non-native invasive species in the San Francisco Bay-Delta, pathways of potential introduction, and tips for preventing new introductions. The RIDNIS project is funded by the CALFED Bay-Delta program.

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## FACILITATING INVADERS AND THE CONSEQUENCES OF THE *SPARTINA* INVASION IN SAN FRANCISCO BAY, CA

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### **Oral Presentation**

10:00 AM, Wednesday

What makes communities more or less invasible has been the focus of much speculation. Traditional ecological theory suggests that systems with higher diversity are less susceptible to invasion by nonnative species than lower diversity systems. Although we now know there are many exceptions to this pattern, when often don't know what the mechanisms are behind these exceptions. One idea is that certain invaders that act as foundation species may facilitate the subsequent invasion of other non-natives species independent of the background native diversity. Our data suggests that this occurs in San Francisco Bay, CA as the result of the *Spartina* hybrid invasion. *Spartina* alters light levels, water flow and sedimentary processes and creates a structural refuge in an otherwise unvegetated habitat. The *Spartina* invasion has resulted in decreased biomass and diversity of native infaunal species, while it has facilitated an increase in the relative abundance of certain exotic species. The mechanisms behind these changes are taxa specific.

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## DEVELOPMENT OF AN EDUCATION AND TRAINING PROGRAM FOR COMMUNITY GROUPS IN ALIEN SEAWEED ERADICATION AND MONITORING

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### Poster Presentation

Monday

Approximately 85% of all U. S. coral reef areas occur within the Hawaiian Archipelago. Many of the corals and native algae that make up these reefs are endemic (found nowhere else in the world), there is no replacement pool to compensate for the loss of these unique species. Some of the most biodiverse and important (both economically and recreationally) reefs in the main Hawaiian Islands are found in Kane'ohe Bay on the island of O'ahu and along the South Maui coastline. Both of these areas have been impacted by blooms of alien algae which have started to result in "phase shifts", where complex coral reef habitat has been replaced by monospecific stands of alien seaweed. At this time, the only control mechanism available is labor intensive hand removal of these destructive seaweeds in such a way as to 1) not damage native algae and corals, and 2) not result in fragments which may spread these destructive seaweeds to new settlement sites. Lacking well-trained manpower in either area, we have developed a formal educational and training program for recognized local volunteer groups in the affected communities in order to develop a long-term eradication program that meets the above two conditions. The program makes use of training manuals and seminars followed by a supervised field program. Outreach and educational components also include an airport informational display, pamphlets and an exhibit at the Waikiki Aquarium.

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## **ALIENS ON THE REEF: CHALLENGES TO MANAGEMENT OF ALIEN SPECIES ON HAWAII'S CORAL REEFS**

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### **Oral Presentation**

3:00 PM, Monday

Aquatic Nuisance Species (ANS) often have life history characteristics which promote rapid spread and rapid growth. Successful ANS tend to be extremely tolerant of a wide range of physiological/environmental conditions, and often tend to be competitively superior at capturing food or nutrients. All of these features make such aliens on coral reefs difficult to control. While ballast water and hull fouling ANS vectors are commonly known for temperate and sub-tropical systems, coral reef ecosystems exposed to ANS have to deal with a suite of additional mechanisms which pose a significant risk to these fragile environments. In Hawaii, at least four out of the five alien seaweeds known to be causing serious problems on the reefs were introduced through research and aquaculture activities. The marine ornamental trade and travel-oriented marine tourism create a new range of ANS challenges and impacts. The vector ecologies involved are quite different from those being dealt with outside of the tropics, and the management concerns and responses vary significantly. Solutions may need to include stronger control and oversight of research and aquaculture activities to minimize accidental introductions, greater support for broad public educational campaigns and targeted efforts at specific marine resource user groups. While more focused research into life history characteristics of coral reef aliens and innovative mechanisms of control is desired, there is a strong need for an immediate and actively-supported program for direct control of those aliens causing complete phase shifts on coral reefs. For many coral reef islands, direct involvement of local communities and the marine tourism industry may provide for the strongest and most effective control mechanisms.

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## ESTABLISHING THE IDENTITY, STATUS AND RISK POSED BY AN INTRODUCED PORTUNID CRAB IN NEW ZEALAND

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### Poster Presentation

Monday

To respond to the incursion of an exotic organism its identity, current status and likely threat must be assessed so that appropriate management actions can be devised. We describe studies that facilitate this process following the discovery of an exotic portunid swimmer crab in northern New Zealand in September 2000. Morphological and DNA analyses were used to establish the crab's identity. Field surveys were undertaken to determine the distribution and relative abundance of the invader in the region where it was first captured by commercial fishers. Pilot experiments were conducted to determine the most efficient sampling methods to detect the crab, and a broad-scale trapping survey was developed adaptively to determine the current limits of its distribution.

By comparing partial cytochrome oxidase I (COI) gene sequences and the morphology of the crab with eight species of *Charybdis*, we identified it as *Charybdis japonica*, a species whose native range stretches from northern China to Malaysia. Trapping surveys at the likely point of introduction showed that *C. japonica* is abundant in a range of habitats in Auckland's Waitemata Harbour. Although the vector of introduction is unknown, ballast water transport to Auckland, New Zealand's busiest port, seems probable. Subsequent surveys indicate the crab is currently restricted to estuarine environments and does not seem to have spread more than 30 km north or south of Waitemata Harbour. This large crab (up to 12cm carapace width) is known to be an opportunistic predator of bivalves, fish, cephalopods and other benthic invertebrates and may have a significant impact on the native benthic fauna of New Zealand estuaries. Management responses to reduce its spread by human vectors are currently being developed by the New Zealand Ministry of Fisheries.

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## RAPA WHELKS (*RAPANA VENOSA*) AS PREY ITEMS FOR CHESAPEAKE BAY FAUNA: NATURAL CONTROLS FOR AN INVASIVE SPECIES?

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### Oral Presentation

4:30 PM, Tuesday

Since the discovery of veined rapa whelks (*Rapana venosa*) in Chesapeake Bay, USA in 1998, over 4000 live rapa whelks have been collected. The Chesapeake Bay rapa whelk population is reproductively active and recruitment to the population by smaller individuals is apparent in observed population demographics. Rapa whelks > 80 mm shell length (SL) probably reach a size refuge from predation by local fauna given the size and strength of the whelks' shell. A series of predator-prey experiments using cultured rapa whelks (SL < 80 mm) as prey items for eleven species of benthic predators including blue crabs (*Callinectes sapidus*), mud crabs (*Eurypanopeus* sp.), oyster toadfish (*Opsanus tau*), and Atlantic croaker (*Micropogonias undulatus*) were conducted in 2001 and 2002. Rapa whelk shell lengths (SL) ranged from 15 - 65 mm. Blue crabs, mud crabs, and spider crabs (*Libinia emarginata*) consumed rapa whelks. Blue crabs > 40 mm carapace width (CW) were voracious rapa whelk predators consuming 73% of rapa whelks offered. Feeding rates of as many as 9 rapa whelks (SL 30-45 mm) per blue crab per day were observed with an average feeding rate of  $3.1 \pm 0.29$  rapa whelks per blue crab per day. Differences in attack methods were observed for blue crabs of different sizes (< 80 mm, 80-120 mm, and > 120 mm CW). Given the probable habitat overlap between juvenile blue crabs and rapa whelks in Chesapeake Bay, predation by blue crabs on epifaunal rapa whelks may be a natural control mechanism for the invasive rapa whelks in Chesapeake Bay and other estuarine habitats.

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**CHANGING DISTRIBUTION PATTERNS IN THE INVASIVE ALGA  
*CODIUM FRAGILE* SSP. *TOMENTOSOIDES*: INTERPLAY OF HERBIVORES  
AND HYDROGRAPHIC CONDITIONS IN THE GULF OF MAINE**

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**Oral Presentation**

9:30 AM, Monday

The invasive canopy alga, *Codium Fragile* ssp. *Tomentosoides*, first observed at the Isles of Shoals in 1983, has become the dominant canopy species to 8 m throughout the islands. *Codium* populations are replacing themselves in what appears to be the new climax species at some sites. However, *Codium* has declined in densities in the protected Gosport Harbor area where it first became established and has only slowly increased its presence in subtidal habitats in the adjacent nearshore coastal zone. Recent studies suggest a combination of factors influencing the relative success of populations between habitats. The herbivore, *Placida dendritica*, may be reducing populations in protected areas in spite of predators such as the green crab, *Carcinus maenas*, while surge may inhibit herbivore buildup in exposed areas. Temperature instability due to localized, wind driven upwelling may be slowing the buildup of subtidal *Codium* populations in nearshore sites. The results will be discussed in the context of what appears to be a still evolving new community state for the Gulf of Maine.

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## **BALLAST WATER MANAGEMENT IN AUSTRALIA**

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### **Poster Presentation**

Tuesday

Vessels providing Australia's international and domestic trade operate out of more than sixty ports along Australia's 37,000 km coastline, and maritime quarantine, natural resource and environmental regulation is a shared responsibility between Australia's federal and seven state governments.

Although, Australia's federal government regulated the discharge of internationally sourced ballast water in July 2001, the discharge of domestically sourced ballast within Australian waters is currently unregulated. This is despite domestically sourced ballast water posing risks of introductions that are equivalent to ballast water of international origin. Moreover ballast water from both sources can be discharged from different vessels visiting the same port and in some instances discharged from the same vessel.

To manage the risks posed by both sources of ballast water a regulatory and administrative model has been trialed at the Port of Hastings, in southeastern Australia. The trial used all vessel movements to the port in the 18 months to 31 December 2002 to assess the physical implementation and environmental effectiveness of the model prior to its intended Australia wide application.

The trial and the subsequent refinement of the model provides a framework for considering issues facing the global community in responding to ballast water. This paper addresses two such issues. First, the implications of shared regulatory responsibility within nation-states. Second, ballast water management options for short voyages that are common, but not limited, to domestic voyages.

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## **CRASSOSTREA GIGAS AS A VECTOR FOR ALIEN SPECIES INTRODUCTIONS IN NORTHWEST EUROPEAN COASTAL WATERS**

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### **Poster Presentation**

Monday

The Japanese oyster *Crassostrea gigas* has been introduced repeatedly and on a large scale to northwest Europe since 1964. The oysters were imported from Japan and the Pacific coast of North America. At present the Japanese oyster has established wild populations in northwest Europe. The oyster transports have provided a pathway for other exotic species; in the North Sea oyster transports are the most important vector for the introduction of non-native species. The aim of this study is to reconstruct the imports of oysters from Japan and North America to northwest Europe. Information from various national resources will be integrated to develop a unified picture. Based on this we will analyze the distribution in time of introductions of Japanese and East-Asian species in northwest Europe.

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## RANKING POTENTIAL NEXT PESTS

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### Oral Presentation

11:00 AM, Wednesday

This paper presents a hazard ranking protocol for potential marine pests. The protocol is simple, does not require large amounts of data, and is capable of grouping hazardous species in to high, medium and low priority. Hazard priority is determined by the invasion potential and impact potential of the species. Invasion potential is expressed as the weighted sum of all vessel movements between the recipient nation and infected bioregions around the world. Impact potential is estimated using a web-based questionnaire.

In 2001, approximately 40% of commercial and recreational vessels movements in Australian waters started their journey in a domestic port. A further 32% started their voyage in just 10 international bioregions. The likelihood of new ship-mediated invasions in Australian waters is therefore critically determined by the distribution of potential marine pests within these ten bioregions.

The potential impacts of an invasive species are dependant on numerous factors and are interpreted very differently by stake holders and interest groups. It is therefore extremely difficult to predict these impacts. In these circumstances it is essential that the degree of uncertainty associated with measurements or estimates of impact is captured and maintained through the analysis. In this analysis we use interval arithmetic to capture the uncertainty surrounding impact estimates because it is simple, intuitive and sufficiently robust in data poor situations.

The hazard ranking procedure developed here is applied to 33 hazardous species, chosen because inter alia they are demonstrably capable of ship-mediated invasion. It is important to recognise, however, that the procedure does not rely on prior invasion history. Indeed it can be applied to any species so long as its world-wide distribution is known and its potential impacts (human, ecological and economic) can be estimated.

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## FROM HEADWATERS TO OCEAN: BUILDING THE CAPACITY OF COASTAL WATERSHED COUNCILS TO ADDRESS AQUATIC INVASIVE SPECIES

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### Oral Presentation

2:15 PM, Wednesday

Successful coastal water quality management programs recognize the importance of adopting a watershed perspective that integrates pollution sources throughout a river basin, its estuary, and the coastal zone. Invaders such as the Chinese mitten crab (*Eriocheir sinensis*), with its catadromous life history, highlight the need for a similar strategy in addressing “biological” pollution that affects coastal ecosystems. Watershed councils have surfaced as a major grassroots force in coastal watershed restoration efforts - nearly 500 watershed groups operate just in California, Oregon, and Washington. These grassroots, volunteer-based organizations play a key role in the assessment, monitoring, and enhancement of river basins and estuaries. However, watershed groups typically have not focused their energy toward aquatic invasive species. Incorporating this issue into watershed assessments and long-term monitoring conducted by watershed councils can greatly expand a region’s capacity to detect new invasions. Similarly, watershed restoration and management plans that include local methods for restricting pathways of introduction can fill in the gaps not addressed by state, tribal, and federal programs.

A multi-state collaborative effort led by Oregon State University and Oregon Sea Grant has begun to assess how to increase the capacity of watershed groups regarding aquatic invasive species management and outreach. Initial investigations reveal that state and regional guidelines for watershed councils are often silent about this issue, focusing primarily on physical habitat enhancement and conventional pollutants, and aiming watershed councils in those same directions. Additional guidance and training is needed to help watershed groups understand how aquatic invasive species can directly affect (and sometimes even unravel) restoration of freshwater and estuarine habitats in a river basin. Given the full plates and limited resources faced by most local watershed groups, effective education and involvement of this audience depends on integrating simple, low-cost methods into their existing watershed monitoring and restoration programs.

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## **“THE CASE OF THE WET INVADERS” – AN AQUATIC INVASION INVESTIGATION KIT FOR THE WEST COAST**

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### **Poster Presentation**

Monday

From Asian copepods to zebra mussels, aquatic invasive species pose significant threats to ecological and economic resources in along the West Coast. Education is critical to preventing new introductions and improving early detection and control capabilities. Based on the successful “Aquatic Exotics” education module and the “Zebra Mussel Mania Traveling Trunk” developed in the Great Lakes, regional educators recognized the educational benefits that would result from a similar portable teaching kit focused on West Coast species and issues. With funding from the National Sea Grant College Program, Oregon Sea Grant has joined forces with the U.S. Fish and Wildlife Service and California and Washington Sea Grant to produce such a product.

Modeled after the Great Lakes tools, “The Case of the Wet Invaders” will facilitate widespread learning about freshwater, estuarine, and marine invasions to youth and adult audiences. As the title suggests, the contents are organized around the theme of a “whodunit” mystery, composed of the following “Case Files”:

“Scene of the Crime”: Introduces the audience to the topic, describing the history of aquatic invasions with an emphasis on the West Coast.

“The Line Up”: Challenges the audience to identify individual species like the European green crab, and provokes critical thinking about definitions such as “alien” or “exotic”.

“Gathering Evidence”: Provides opportunities for evaluating ecological, social, and economic impacts.

“Profiler”: Engages the audience in the difficult task of predicting when non-native species introductions will lead to problems, and explains common traits of invaders.

“Setting Up Roadblocks”: Emphasizes the benefits of preventing invasions and illustrates the variety of pathways that lead to introductions.

“Crackdown”: Involves the audience in tough choices about dealing with existing aquatic invasive species populations, and presents information about various control methods.

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## PLASMID-BORNE ANTIBIOTIC RESISTANCE IN *VIBRIO CHOLERA*E ISOLATED FROM SHIPS' BALLAST WATER

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### Poster Presentation

Monday

Resistance to antibiotics is common in *Vibrio cholerae* (the causative agent of human cholera) isolated from ships' ballast tanks. The genes encoding antibiotic resistance may reside on plasmids, small extra-chromosomal DNA molecules that can be transferred between bacterial cells. Plasmids were extracted from *V. cholerae* isolated from ballast tanks, then characterized based on their size using gel electrophoresis. A restriction map will be generated to further elucidate the genetic structures of these plasmids. Polymerase Chain Reaction (PCR) will be used to determine the location of the genes responsible for antibiotic resistance. The identification and characterization of plasmids found in bacteria in ballast tanks will help assess the potential for nonindigenous, possibly invasive genotypes to affect native populations.

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## THE SPREAD OF THE CHINESE MITTEN CRAB (*ERIOCHEIR SINENSIS*) IN EUROPE: DOES THE PAST EXPLAIN THE PRESENT?

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### Oral Presentation

11:30 AM, Tuesday

The Chinese mitten crab, *Eriocheir sinensis*, is an invasive species that lives predominantly in freshwater but migrates seawards to breed. It has spread via ballast water and/or intentional introduction to Continental Europe, Southern France, USA (San Francisco Bay) and the United Kingdom. Analysis of detailed historical data from the outbreak in Europe was digitized and analyzed using Geographical Information Software. This revealed that there were two separate invasions in Northern Europe and Southern France, with an increase in the average total distance of upstream migration during the peak period by 1028 km/year during 1928-1938 (Northern Europe) and 443 km/year (1954-1960) in Southern France. Beside the spread inland via rivers and canals, the rate of coastal spread has been assessed as an average of 540km/year for 1926-35 and 346 km/year for 1942-1954. The current expansion in the Great Britain follows a similar pattern. The rate of range expansion along the coast is one order of magnitude higher than that observed for *Carcinus maenas* on the east or west coast of North America or in South Africa.

Further analysis of the historical size class distribution data from lower estuary of the River Elbe (Germany) illustrates migration patterns to and from the estuary over the year. Marking experiments determined that the mean rate of downstream migration for adults was 11.5 km/day, up to a maximum of 18.1 km/day. The peak period for upstream migration was March to July, followed by the downstream season from July to September. This data set, extracted from historical references, represents one of the most complete pictures of the life cycle and spreading behaviour of this alien invader.

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## INVASIVE SPECIES MONITORING: APPROACHES FOR VOLUNTEER PROGRAMS

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### Poster Presentation

Monday

Extensive research conducted on the subject of controlling invasive species suggests that prevention and early detection is the most effective approach, economically and practically. Training volunteers to monitor for invasive species can significantly enhance both prevention and early detection. Clearly, having more eyes in more places watching for potential invasive species will greatly improve the possibility of identifying a new invasion quickly, maybe at a point when eradication is more feasible. In addition, volunteer monitoring efforts can help assess the consequences of bioinvasions. The frequently more comprehensive, long-term monitoring data gathered by volunteer programs can be used to identify changes in ecological conditions. With proper training, and good timing, volunteers can also provide baseline data on relevant species, as well as assess impacts once a bioinvasion has occurred. Perhaps more important is the role volunteer monitoring plays in preventing the spread of invasive species through education, and the development of an informed community and local stewardship.

Monitoring for invasive species, or baseline community assessments can occur as a stand-alone program, or as part of a larger water quality monitoring effort. Various approaches will be presented, with existing programs highlighted. Particularly useful websites and program contacts will also be provided to help you develop your strategy for monitoring invasive aquatic species with the help of volunteers.

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## **BALLAST WATER TREATMENT EXPERIMENTS WITH OZONE ON BOARD THE OIL TANKER S/T TONSINA**

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### **Poster Presentation**

Tuesday

Ballast water has been suggested as a major vector for the introduction of aquatic nuisance organisms around the world. Several treatment technologies are proposed for removing or inactivating organisms present in ballast water. A multidisciplinary research team examined the efficacy of a prototype ozone treatment system installed on the commercial oil tanker S/T Tonsina for inactivating microorganisms, phytoplankton, and zooplankton present in ballast water. Ozone was generated on board the ship, distributed by stainless steel tubing, and bubbled into a ballast tank through diffusers. Shipboard experiments using Puget Sound seawater were conducted. Water samples were collected from experimental and control tanks using Niskin oceanographic samplers and by a installed tubing system. Zooplankton samples were collected by performing vertical plankton tows. Four species of bioassay organisms (sheepshead minnow, mysid shrimp, shore crab, amphipod) were suspended in experimental and control ballast tanks. Whole effluent toxicity (WET) tests were performed. The primary objective of the shipboard experiments was to evaluate the chemistry and biology of ballast water treated with ozone versus the properties of a control ballast tank. In addition, a mid oceanic exchange was conducted. The first phase of the research determined if ozone treatment was effective and comparable to ballast water exchange. In the second phase, latent toxicity of ozone and its by-products were examined in shipboard and laboratory mesocosm experiments. The goal of the second phase was to reduce the amount of ozone required to inactivate organisms. Results of the shipboard experiments showed that ozone treatment was extremely effective against microbial populations, including heterotrophic bacteria and phytoplankton. Zooplankton in the ballast water were also largely inactivated. Performance of the prototype system was promising, but our results suggest that additional research and engineering design changes should be considered.

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## BIOPROVINCES AS SURROGATES OF ‘TARGET’ SPECIES FOR IDENTIFYING INVASION HAZARD

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### Oral Presentation

11:15 AM, Tuesday

Risk assessment has proven a useful tool to management, however environmental risk assessment has proven elusive. Nonetheless, risk assessment methods are being applied to discrete elements of the ballast water cycle (uptake, transit survival, and discharge). Several countries have adopted a ‘target’ species approach to assessing risks, however, our ability to identify the current extent of invasions in marine environments is poor due to limited taxonomic knowledge and sampling effort. These issues combined with the risks posed by ‘non-target’ organisms has led some groups to an alternative approach – environmental matching, which seeks to use the environmental similarity between two regions (e.g. between the donor and recipient ports) as a surrogate measure of bio-invasion risk. Such risk assessments avoid the question, “which species will be the next invader” but assume that the likelihood of invasion is directly proportional to the biophysical similarity between donor and recipient environments. This assumption is unlikely to encompass the true risks since the organisms contribute little information to the assessment. Here we evaluate the utility of biological provinces as a non-target specific means of determining invasion risk. Species with documented invasion histories were assessed, comparing: 1) individual species’ physiological tolerances versus their native provincial distribution’s environmental extremes to demonstrate the representative nature of provinces; and 2) for each species, their native provincial distribution’s environmental extremes versus the environmental extremes of their invaded bioregions. With few exceptions, the environmental extremes of the biological provinces were conservative predictors of species’ physiological tolerances, and of the successfully invaded bioregions.

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# IDENTIFICATION OF COASTAL ZONES USING SATELLITE-DERIVED OCEAN COLOR AND TURBIDITY: IMPLICATIONS FOR BALLAST WATER EXCHANGE ZONES

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## Poster Presentation

Monday

Ballast water is well recognized as a principal vector for the introduction of marine species and management of ballast exchange is receiving increased attention around the world. The water adjacent to the coast (and hence ports) is often referred to as the coastal zone. The coastal zone is a high-risk area for the discharge of ballast water, as many organisms can settle in or arrive at the coast from these waters. Oceanic waters are found beyond the temporally and spatially fluctuating coastal zone. Ballasting activities that occur seaward of the coastal zone are expected to reduce the risk of establishment or transfer of marine pests. Determining the extent of the coastal zone around a country or port will allow waters suitable for the exchange of ballast water to be identified.

We estimated the boundary between coastal and oceanic water around Australia using historical data from the SeaWiFS satellite sensors. These data comprise (i) color, used as a proxy for chlorophyll a, and (ii) diffuse attenuation coefficient, used as a proxy for turbidity. The coastal zone is high with regard to these variables, and the edge of the coastal zone is identified by declines in the values in an offshore direction for each satellite image. The distances from the coast (and from an example set of 44 Australian ports) are used to compare a range of different probability baselines. The distance of baselines from the coast increases with decreased probability (i.e. lower risk probability baselines are further offshore).

These baselines could be applied to management of ballasting activities for coastal short-duration domestic and to long-duration international shipping; however, in some regions of Australia the baselines are significant distances offshore and in such regions may not provide an effective management solution for coastal shipping.

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## MARITIME MAMMALS: INTRODUCED TERRESTRIAL MAMMALS AS PREDATORS IN MARINE INTERTIDAL COMMUNITIES

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### Oral Presentation

9:45 AM, Tuesday

Maritime mammals are coastal terrestrial mammalian predators that consume living intertidal organisms, transferring these resources (as energy subsidies) to the land. We asked if introduced mammals prey in the intertidal zone, and, if so, what their prey and biogeographical distribution are. Introduced populations of 17 species of mammals (in four orders, Lagomorpha, Rodentia, Carnivora, and Artiodactyla) have been reported as maritime predators from all oceans (North and South Pacific, North and South Atlantic, and the Indian Ocean). Fifteen of these species are recorded solely or in part on islands, where endemic mammals are absent or rare (perhaps making predation more obvious). A wide variety of prey are taken (sponges, mollusks, crustaceans, echinoderms, polychaetes, fish, and algae). Three maritime mammals utilize, in part, introduced prey. The native false water rat in Australia, the native raccoon in California, and the native mink in Maine all prey on introduced populations of the European crab, *Carcinus maenas*, while native raccoons on the Pacific American coast prey on introduced clams. In only one instance is there a record (from Oregon) of an introduced mammal (pigs) preying upon introduced prey (the Atlantic clam, *Mya arenaria*). Overall, 45 species of maritime mammals are now known, and thus comprise a large and largely overlooked guild of intertidal predators. We suggest research programs based upon quantitative data collection and experimental studies in order to assess the potential importance of mammalian intertidal predation on altering the abundance, distribution, and diversity of their prey.

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## AN INVASIVE CRAB IN THE SOUTH ATLANTIC BIGHT: FRIEND OR FOE?

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### Poster Presentation

Tuesday

Biological invasions can threaten natural communities by altering the forces determining ecosystem structure and function. The green porcelain crab, *Petrolisthes armatus*, recently invaded oyster reefs of the South Atlantic Bight in densities of up to several thousand crabs/m<sup>2</sup>, but the effects of this invasion remain undetermined. Therefore, the focus of our research addresses the ecological implications of this invasion. In order to perform experiments relative to our concerns at the local, regional, and community-wide scales, we “recreated” oyster reefs in independently treated and replicated baskets within ten flow-through mesocosm tanks at the Skidaway Institute of Oceanography, Savannah, GA. The treatments included oysters from which all organisms were removed and combinations of locally dominant crab species at realistic densities. The combinations were: (1) no crabs, (2) mud crabs (*Panopeus herbstii*), (3) mean June density of porcelain crabs + mud crabs, and (4) 3x mean June density of porcelain crabs + mud crabs. These “communities” were maintained for several months. The sediments and growth on the oysters were monitored over time, and at completion all organisms were documented, assessed for growth and survivorship, physical and reproductive condition, and recruitment success. Preliminary data suggest that oyster settlement was more successful when there were no crabs and that mud crabs caused considerable damage to oysters and mussels when no porcelain crabs were available as an alternate food source.

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## BUILDING COMMUNITY AWARENESS AND INVOLVEMENT IN ALIEN SPECIES ERADICATION

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### Oral Presentation

12:15 PM, Monday

An alliance of federally-funded researchers (Hawaii Coral Reef Initiative Research Program), state resource managers (Hawaii Department of Land and Natural Resources), non-governmental agencies (The Nature Conservancy and Reef Check), community volunteers (canoe clubs, campus clubs, and individuals) and private sector entrepreneurs (green-waste recycling, dive tour, and restaurant businesses) collaboratively organized to involve community volunteers in an educational and environmentally effective effort to remove alien algae from a state Marine Life Conservation District (MLCD) in Waikiki, Hawaii. Over the past 25+ years, the reef area within the MLCD has been increasingly overgrown by the alien alga, *Gracilaria salicornia*, introduced for aquaculture research in the 1970's. This reef once evidenced over 60 species of macroalgae with up to 7 kg of wet weight biomass per m<sup>2</sup>. Only 29 macroalgal species were recorded in the same area in 2002, with *G. salicornia* alone accounting for over 10 kg of the wet weight biomass per m<sup>2</sup>. Summer swells dislodge large amounts of this biomass from its attachment on the reef, producing asexually viable, rafting propagules and forming extensive wash-ups on Waikiki Beach.

Volunteer divers, snorkelers, beach toters, weighers, algal sorters, and recorders have been organized to focus on removal of the alien algae during weekend mornings. The algae is transported to a green-waste recycling company which uses it to produce composting tea; local gardeners and farmers are also experimenting with composting and nutrient-enrichment uses for the alien seaweed. Preparation of an educational brochure and press releases to prime media coverage have contributed to the one of the most important outcomes of the effort: an increased public and political awareness of the ecological threat of alien algae to Hawaiian reefs. Over 10 tons of alien algae have been removed from the MLCD in three morning efforts involving 200+ community volunteers.

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## DESIGN AND EFFECTIVENESS OF MARINE PEST SURVEILLANCE IN NEW ZEALAND

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### **Oral Presentation**

11:15 AM, Wednesday

The chances of controlling or eradicating an outbreak by an exotic species are greatest if the interloper is detected early, before it has the opportunity to spread widely and become abundant. Surveillance monitoring is widely used for the early detection and containment of agricultural pests, but has received little consideration in the management of marine pests. The New Zealand Ministry of Fisheries has identified seven species that pose a significant risk to native marine resources should they become established in the country. In this paper, we describe the process undertaken to design a national surveillance programme for these pests and ways to evaluate its effectiveness. Risk profiling of shipping movements was used to identify eight high-risk points of entry into the country for the pests. In each of these locations, hydrodynamic models and predictive habitat modelling are being used concurrently to direct field sampling to areas where the chances of early detection are greatest. Hydrodynamic models are used to simulate the likely movement of discharged ballast water and the larvae of pest species from potential release points in the harbours. These simulations are then overlaid onto spatially explicit models of the preferred habitats and environmental tolerances of each of the target species. We discuss approaches to sampling and ways in which appropriate sampling effort and confidence of detection can be estimated for the target species.

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## CARTOGRAPHY AND RISK ASSESSMENT OF THE DEVELOPMENT OF THE ALGA *CAULERPA TAXIFOLIA* IN THE NORTHWEST MEDITERRANEAN

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### Poster Presentation

Tuesday

From 1997 to 2000, we mapped 44% of the total area reportedly colonized by *Caulerpa taxifolia*, to a depth of 20 m on the south coast of France, by combining airborne multispectral imaging with underwater survey. High-resolution images of shallow marine habitats (<20 m) were obtained under optimum meteorological conditions using a compact airborne spectrographic imager (casi). Images were acquired in autumn to coincide with the maximal annual abundance of *Caulerpa taxifolia*. Underwater surveys and measurements of the optical properties of water were carried out concomitantly by divers so as to provide data for casi image processing and production of thematic maps. All of the data were geo-positioned on the Universal Transverse Mercator with an accuracy of  $\pm 3.6$  m. Data collected with the casi were positioned using a differential geographic positioning system and data collected underwater using an acoustic interferometer. The thematic maps were validated using direct underwater observations of selected stations. Results of these surveys show that combining high-resolution multispectral images with data collected concomitantly underwater can produce extremely accurate maps of shallow marine habitats. They confound existing claims regarding both the cover of *Caulerpa taxifolia* and the alga's capacity to overgrow the native seagrass, *Posidonia oceanica*. Significant development of the alga is confined to substrata that appear to be contaminated by anthropogenic waste in marinas and a limited number of localities in the vicinity of urban sewage outfalls and storm water drains. *Caulerpa taxifolia* principally occupies partially vacant niches in stressed environments; thus the risk to most endemic species, if any, should be considerably lower than formerly predicted.

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## INTRODUCTION, SPREAD AND POTENTIAL IMPACT OF THE RECENTLY INTRODUCED RED KING CRAB, *PARALITHODES CAMTSCHATICUS*, IN COASTAL SUBARCTIC NORWAY

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### Oral Presentation

4:00 PM, Tuesday

In the 1960s the red king crab, *Paralithodes camtschaticus*, was intentionally released in the Russian Barents Sea to create a new and valuable fishing resource in the region. About 30 years later it became abundant in Norwegian part of the Sea. Today the king crab is known to hatch at several places in Norwegian waters with frequent abundant year-classes, and the steadily increasing numbers of crabs are invading new coastal areas.

In the crabs' native area, the Bering and northern Pacific Seas, specimens with a weight of 12 kg and ages up to 25 years has been recorded. In this area the crab occupy depths between 4 and 300m and a habitat temperature between -1.7 and 11 degrees Centigrade. The crab performs extensive annual migrations from deep waters in the winter months, to shallow waters in the spring. In shallow waters they aggregate in large groups, mate, breed and molt. After the mating and breeding the king crab feed most intensively. The king crab predate on several groups of bottom animals and is questioned to have a significant impact on the benthic fauna, but this influence has yet been poorly documented.

The spread of the king crab to new areas provides a rare opportunity to observe in progress a biological invasion of benthic communities and to observe any community-level alternations as they occur. To predict the impact of this non-native species, putative impacted and randomly selected control locations are followed using long-term monitoring. Experimental studies in the laboratory and the field is carried out in order to reveal the mechanisms by which this introduced species may alter and influence community structure.

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## A PREDATION SIGNATURE-BASED KEY TO ATTRIBUTE PREDATION UPON BIVALVES TO NATIVE VERSUS INVASIVE GASTROPODS

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### Poster Presentation

Tuesday

In the Chesapeake Bay region, small (< 70 mm, SL) non-native *Rapana venosa* are generalist gastropod predators in shallow hard substratum environments, whilst larger individuals occupy an infaunal soft sediment niche in deeper water. As such *R. venosa* has ecological and economic implications for both epifaunal and infaunal bivalve species in the Bay area. Spatial separation of size classes, rapid growth rates, cryptic colouration, nocturnal activity, and the size-selective nature of fishing gear, determine that small *Rapana venosa* are rarely collected as a by-catch of commercial fishing activity. An indirect method of detection, therefore, may provide an earlier indication of this invader.

A predation signature based key, capable of differentiating between predator species, would be one such method. A range of bivalve species were recovered from experiments involving *Rapana venosa* and native gastropods, *Urosalpinx cinerea* and *Eupleura caudata*, and examined for predation signatures. *Rapana venosa* < 20 mm SL produced drill holes in the valves of oysters, however, *R. venosa* > 40 mm SL rarely produced unambiguous signatures in oysters and clams. Predation signatures from *Rapana venosa* were never found for *Geukensia demissa*. In contrast, all instances of predation involving *Urosalpinx cinerea* and *Eupleura caudata* consuming *Crassostrea virginica*, *Geukensia demissa*, and *Mercenaria mercenaria* resulted in characteristic drill holes in the prey valves.

The absence of *Rapana venosa* predation signatures in a high proportion of prey examined is problematic in terms of distinguishing between sources of mortality in the field. Development of a predation signature key involving morphological characters of drill holes produced by small *Rapana venosa*, *Urosalpinx cinerea*, and *Eupleura caudata*, however, may allow the detection of recently recruited *Rapana venosa* from shell valves collected in the field. Such information has valuable applications to ongoing research into oyster reef restoration and the monitoring of the spread of *Rapana venosa*.

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## SECONDARY INVASIONS OF MARINE PESTS - ANALYSING DOMESTIC TRANSPORT VECTORS IN THE AUSTRALIAN MARINE ENVIRONMENT

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### **Oral Presentation**

11:30 AM, Wednesday

Recently, attention has been focussed on the translocation of marine organisms across international frontiers, primarily via the medium of ballast water carried by global commercial shipping. In contrast, the subsequent dispersal of introduced pests through domestic territorial waters has been somewhat overlooked, despite the enormous potential for escalating impacts on inshore marine ecosystems that support productive fisheries and aquaculture industries. In a number of high-profile cases in Australia, it has been documented that human-mediated agents such as yachts and commercial fishing boats have been responsible for spreading pest species beyond their initial point of entry and prompt action to control the movements of such vessels has resulted in at least one successful eradication of the introduced black-striped mussel in Darwin. In order to address this issue of domestic translocation of introduced marine pests, we compiled, analysed and mapped data relating to the movements of anthropogenic vectors in Australian waters within a geographic information system (GIS). The GIS contains spatially explicit information on the frequency, volume, direction, range and promiscuity of a diverse array of vectors such as merchant shipping, recreational and commercial fishing vessels, pleasure craft, oil rigs, and cruising yachts as well as the 'nodes' from which they operate (marinas, boat ramps, moorings). This is the first step towards developing a spatial decision support system (DSS) that can be applied both as a strategic planning and emergency response tool. Information on vector pathways will be combined with data on entrainment probabilities being gathered from other studies to assess the relative risks of translocation of different species from a particular point of infection by various vectors and determine which vectors present the greatest hazard in a given situation. This knowledge can be used either in scenario planning exercises or to guide action in the event of detection of a new pest incursion.

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## EFFECTS OF THE INTRODUCED POLYCHAETE (*MARENZELLERIA VIRIDIS*) ON THE SIMPLE ECOSYSTEM OF THE NORTHERN BALTIC SEA

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### Oral Presentation

4:30 PM, Monday

Owing to isolation, short developing time, low salinity and large fluctuations in temperature only a limited number of species have been adapted to the conditions of the Baltic Sea. Low species diversity together with the extensive anthropogenic impact make the region potentially invasion prone. A number of benthic animals presently living in the Baltic have only recently invaded the area, some only in the last decades or years.

The North-American polychaete (*Marenzelleria viridis*) was introduced to Europe at the beginning of the 1980s. The polychaete has quickly spread to most parts of the North and Baltic seas. The species prevails in many coastal areas of the northern Baltic Sea. The establishment of *M. viridis* has been more successful either in more eutrophicated regions or in more uniform biotopes.

Concurrent with this invasion the densities of the amphipods (*Corophium volutator* and *Monoporeia affinis*), the polychaete (*Nereis diversicolor*) have dropped considerably. *M. viridis* has become an important food item for some benthophagous fishes.

Field experiments combining natural densities of native macrofauna and the introduced polychaete showed that the effects of *M. viridis* on the sublittoral community ecology were many and varied. The presence of *M. viridis* increased benthic production. *M. viridis* reduced the growth and survival of *N. diversicolor* and *M. affinis*. This effect decreased with the increasing density of adult specimens of the bivalve *Macoma balthica*. Competitive interactions between *M. viridis* and *M. balthica* appear a key factor limiting the distribution of *M. viridis* in the northern Baltic Sea. Competitive superiority of *M. balthica* over *M. viridis* is likely due to more efficient feeding regime of the bivalve. To conclude, owing to its unprecedented invasion success, dominance in many biotopes and effects on the native fauna the polychaete may be ranked among the most influential exotics in the northern Baltic Sea.

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## **PUBLIC PERCEPTIONS OF INVASIVE SPECIES: MEDIA TRENDS IN NEWSPAPER ARTICLES, 1992-2002**

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### **Oral Presentation**

3:45 PM, Wednesday

Since the re-emergence of the environmental movement in the late 1980s, invasive species have received increasing attention from both the scientific community and popular press. There is a lack of consensus, however, in the terminology describing this ecological threat. Some popular terms are “exotic,” “alien,” and “invasive.” Frequently, these terms are combined (e.g. “exotic alien species”) and are used interchangeably despite the fact that a species can be nonnative without being harmful. The variety of monikers can distract from the underlying issues and can create confusion among policymakers and the general public.

This study investigates trends in newspaper coverage of invasive species by analyzing terminology used by the media to describe this phenomenon. Lexus-Nexus databases were searched for newspaper articles containing the terms “exotic species,” “invasive species,” “alien species,” “nonnative species” and “non-native species,” “nonindigenous species,” “nuisance species,” “introduced species,” and “foreign species.” Each article was examined to determine if the subject was truly relevant to invasive species issues. For example, if the term “exotic species” was used to describe animals in a zoo, the article was excluded.

Initial results indicate that invasive species are getting more media attention, but terminology trends are changing. Reporters are moving away from “exotic species” as the primary term and are increasingly using “invasive species.” There is also a decline, though not as dramatic, in the use of “foreign species,” while “introduced species” is increasing slightly. Usage of the other terms has remained fairly constant over the last decade.

Future analyses will include Lexus-Nexus searches for articles on specific invasives to determine variations in species coverage, their geographical patterns, and trends through time. The ultimate goal is to assist scientists and managers in speaking with a unified voice while conveying invasive species issues to the public.

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## HOST SPECIFICITY: AN EXPERIMENTAL EVALUATION FOR A PARASITIC CASTRATOR, *SACCULINA CARCINI*, AND AN INAPPROPRIATE HOST CRAB, *PACHYGRAPSUS MARMORATUS*

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### Oral Presentation

4:15 PM, Wednesday

In the context of safety tests for the rhizocephalan parasitic castrator, *Sacculina carcini*, as a natural enemy of introduced populations of the green crab, *Carcinus maenas*, we were able to infect several species of native California crabs. These experiments intentionally wedged open the encounter filter and maximized chances for infection in small volumes of water with its natural host present, presumably providing chemical cues. Although these California crabs were readily infected, the rhizocephalan could not develop normally in those crabs. All infected California crabs died without producing the reproductive externa of the parasite, often showing severe neurological sequelae shortly before death. This prompted us to examine the ability of *S. carcini* to infect an inappropriate host from its native Europe, *Pachygrapsus marmoratus*, under experimental circumstances identical to those used to infect California crabs. *Pachygrapsus marmoratus* is closely related (congeneric) to one of the California species, *P. crassipes*, that died following infection by *S. carcini*. *Pachygrapsus marmoratus* was readily settled upon by *S. carcini* cyprids. However, the internas did not develop. In the thoracic ganglion, the site of early development of the parasite, we could only detect small melanized spots. Since the abundance of these spots was proportional to the abundance of attached cyprids and since a molecular probe detected the presence of *S. carcini* DNA in these crabs, we interpreted the spots to be early infections that were always successfully killed by the host response melanization of *P. marmoratus*. Hence, the compatibility filter for *S. carcini* was closed in *P. marmoratus*.

We then used this response as an assay for the frequency of attack by *S. carcini* on *P. marmoratus*. In other words, we were able to get a direct estimate of the importance of the encounter filter for this host by examining the frequency of melanized spots in the thoracic ganglion of *P. marmoratus* in the Mira River estuary in Portugal. Here, green crabs are heavily infected (~50% prevalence). Both *P. marmoratus* and *C. maenas* are common, and are often found under the same rock. For a control population, we used an outer coast location, Sao Torpes, 20 km north of the Mira River estuary, which lacked green crabs (the Mira River is the closest green crab population). A control is necessary because any foreign body can elicit a melanization response. We could find no evidence of attack by *S. carcini* on *P. marmoratus* in the Mira river estuary. The Sao Torpes crabs had a slightly higher melanization frequency than did the Mira river estuary population. Consequently, we conclude that the encounter filter for *S. carcini* locating *P. marmoratus* is also enclosed. This is the first direct estimate of attack rates by a rhizocephalan on a non-host and one of the few such quantitative observations for any parasite on any host. This demonstration of the role of the encounter filter for host specificity of *S. carcini* shows that the host location must be analyzed to effectively evaluate the safety of natural enemies as biological control agents.

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## EELGRASS HABITAT STRUCTURE AND THE DENSITY-DEPENDENT MORTALITY OF AN INVASIVE BIVALVE

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### Poster Presentation

Tuesday

Eelgrass (*Zostera marina*) habitat structure often strongly influences predator-prey dynamics in shallow coastal waters. We investigated the impact of eelgrass habitat structure (= shoot density) on proportional mortality in the exotic mussel, *Musculista senhousia*, which reaches extremely high densities in eelgrass habitat in Mission Bay, San Diego. In a fully factorial design, mussels (40, 80, 160, 320, 640, and 1280/m<sup>2</sup>) were exposed to predators in 0.05 m<sup>2</sup> artificial seagrass plots of four different shoot densities (0, 300, 600, and 1800 shoots/m<sup>2</sup>) in replicate 2 d trials in the summer of 2002. Mussel proportional mortality was inversely density-dependent in all shoot density treatments. Over 90% of mortality was due to a gastropod predator *Pteropurpura festiva*. These snails exhibited a hyperbolic aggregative response to mussels, resulting in fewer predators per mussel at high mussel densities. The predatory snail was so abundant at our site however, that mussels exposed for 7 d all were consumed regardless of mussel density. High snail abundance may have been due to a nearby rock jetty that served as a source of snails to eelgrass beds. Predatory snails are less abundant and *M. senhousia* more abundant in areas of Mission Bay without rocks. *Musculista senhousia* may find a refuge from predators by living in high densities within eelgrass habitat, except where premium habitat exists for its chief predators.

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## **FECAMPIA ERYTHROCEPHALA, A PARASITOID NATURAL ENEMY OF THE EUROPEAN GREEN CRAB, CARCINUS MAENAS**

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### **Oral Presentation**

5:00 PM, Wednesday

*Fecampia erythrocephala* is a flatworm (Class Fecampiida) that infects *Carcinus maenas* and *Cancer pagurus* on the Isle of Man and near Plymouth, England. It has a direct life cycle and adults secrete cocoons on the underside of rocks. Both infected crabs and cocoons are most common in the knotted wrack (*Ascophyllum*) and serrated fucus (*Fucus serratus*) zones. *Fecampia erythrocephala* did not infect crabs greater than 11 mm carapace width and prevalence decreased with crab size. Prevalences reached 11% in areas where cocoons were abundant. The large size of these worms, declining prevalence with size and observations on emergence indicate that these worms are parasitoids. Infection invariably leads to death of the host. Cocoon abundance is often locally high and size-prevalence data suggest that worms mature rapidly in these crabs. This implies that *F. erythrocephala* is an important contributor to green crab mortality and to the ecology of shore crabs at some sites. Comparison with insect parasitoid models indicates that *F. erythrocephala* has potential as a natural enemy for biological control of green crabs. However, its habitat specialization will limit its use to only a subset of green crab habitats. Because it is locally common, and can probably be readily cultured, studies of its biology, most particularly its host specificity, are likely tractable and fruitful. Its safety as a natural enemy of exotic green crab populations will depend on its host specificity, and on its encounter rates with young green crabs versus non-target native crabs.

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## TRANS-HEMISPHERE INVASION OF THE SOUTH-TEMPERATE AND SUBANTARCTIC ASCIDIAN *CORELLA EUMYOTA* TRAUSTEDT, 1882, INTO TWO HARBORS IN BRITTANY, FRANCE

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### Oral Presentation

9:45 AM, Wednesday

*Corella parallelogramma* is the only *Corella* species recorded from the English Channel region of France. However, during July and August 2002 we found numerous large clumps of *C. eumyota* on ropes and floats at the marinas at Perros Guirec and Camaret-sur-Mer in western Brittany on the English Channel. Our identifications are based on a careful comparison with specimens from southern New Zealand and South Africa of the adult and egg morphology, and the fact that it is a brooder. Several thousand embryos are ovulated directly into the peribranchial cavity where they stick together in a cohesive gelatinous mass. The tadpoles are retained for several hours after hatching and are not released until they are competent to settle. Larval life outside the adult is therefore very short, perhaps only a few minutes; as a result the larvae settle near or on the adults and large heavy clumps result. The individuals are very tightly cemented together and often impossible to separate without tearing the tunics. *C. eumyota*'s previously known range has been limited to the southern hemisphere, where it is abundant and widespread in south temperate, subantarctic, and Antarctic waters: South Africa, S. America, south Australia, Tasmania, and New Zealand from Auckland to the south tip of the south island. This species was not present 5 years ago (our last visit to Brittany) at the 2 marinas where we found it abundantly this year. It has the potential to become a serious pest for the mussel culture industry in Normandy. We do not know how widespread it is in Europe but colleagues in the UK have not seen it. This may be the first record of a southern to northern hemisphere range extension for an ascidian, although several species are known to have been transported from Europe to the southern hemisphere.

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## HOW INVADED IS INVADED?

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### **Oral Presentation**

2:00 PM, Wednesday

One thrust of invasion biology has been to compare the extent of invasion among communities and biogeographic regions. A problem with such comparisons has been the plethora of metrics used and the lack of standardization as to what data are incorporated into the metrics. One source of variation is whether the cryptogenic species, the species of unknown origin, are included in the counts of non native species. Another source of variation is the indeterminate taxa, the taxa not identified with sufficient taxonomic resolution to classify them as native or nonindigenous. Indeterminate species can constitute a sizable proportion of the individuals and taxa in benthic studies, and thus impact metrics based on percentages. Yet another source of variation is the spatial scales over which the metrics are calculated, which can range from measures on individual samples to entire biogeographic regions. To explore the variation these different approaches introduce, we calculated a suite of metrics for both highly invaded soft bottom communities (San Francisco Estuary) and for low to moderately invaded systems (EMAP survey of the small Pacific coast estuaries). These results suggest that differences among the approaches can equal or exceed differences expected among estuaries. For example, the percentage abundance of non native species in the EMAP survey ranged from 6.5% to 28.7% depending on how the value was calculated. The effect of spatial scale on species richness is demonstrated by the decrease in the percentage of the species composed of nonindigenous species from 42% at the grab scale to 11% at the estuary scale in the San Francisco Estuary. Because of these sources of variation, it is critical for researchers to report exactly how their estimates of the extent of invasion were calculated and to compare only metrics calculated in the same manner and over the same spatial scale.

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## REGIONAL ASSESSMENT OF THE INVASIVE MACROBENTHOS IN THE SMALL WEST COAST ESTUARIES

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### Poster Presentation

Monday

In 1999, U.S. Environmental Protection Agency's (EPA) Environmental Monitoring Assessment Program (EMAP) surveyed the soft bottom benthic communities in the estuaries of California, Oregon, and Washington exclusive of the large systems (i.e., Puget Sound, Columbia River, and San Francisco Bay which were sampled in 2000). Out of a total of 677 benthic species, 43 were nonindigenous and 88 were cryptogenic. The polychaetes, *Pseudopolydora paucibranchiata* and *Hobsonia florida*, and the amphipods, *Grandidierella japonica* and *Corophium acherusicum*, were the most abundant nonindigenous species in these small West coast estuaries. The polychaetes, *Streblospio benedicti* and *Pygospio elegans*, were the most abundant cryptogenic species. In contrast to the importance of polychaetes among the nonindigenous and cryptogenic species, amphipods were the numerical dominants among the native species, in particular two species of *Corophium*. The EMAP probabilistic survey design allowed statistically unbiased estimates of the area invaded as measured by different metrics. No nonindigenous species were collected in approximately 30% of the estuarine area. In contrast, nonindigenous species constituted  $\geq 50\%$  of the individuals in 2.5% of the area. If the cryptogenic species were included, non native species were the numerical dominants in 18% of the area. As measured by the percentage of the species per sample, nonindigenous species were the major component of species richness in 7.5% of the area of these estuaries. This estimate increased to 25% of the area if the cryptogenic species were included. These results provide the first regional-scale evaluation of the nature and extent of invasion of the estuaries on the West coast.

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## CHANGES IN WETLAND FOOD WEBS ASSOCIATED WITH PLANT INVASION: USE OF STABLE ISOTOPIC ENRICHMENT EXPERIMENTS

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### Oral Presentation

2:45 PM, Monday

Vascular plant invasion of unvegetated marine sediments typically leads to alteration of food available to marine benthos. Effects are direct, through increased supply of plant detritus to sediments, and indirect, through modification of environmental factors (e.g., light, flow, moisture) that regulate availability of other primary producers such as phytoplankton and benthic algae. Invasion of south San Francisco Bay tidal flats by a *Spartina alterniflora/foliola* hybrid has led to a reduction in some benthic taxa and increased dominance by in others. By introducing  $^{15}\text{N}$ -labeled *Spartina* detritus and  $^{13}\text{C}$ -labeled microalgae into marsh and mudflat sediments, we have been able to determine, in combination with natural abundance stable isotopic composition, which benthic taxa consume different food sources. Isotopic data suggest that subsurface, burrowing deposit feeders (capitellid polychaetes and tubificid oligochaetes) in this system can utilize *Spartina* detritus most readily; these are also the taxa that assume greater importance in invaded patches. Selected surface-feeding taxa whose abundance typically declines during *Spartina* invasion appear more reliant on microalgal production for nutrition. These observations suggest that bottom-up processes can contribute strongly to benthic community shifts following marsh plant invasion. Trophic succession appears to provide a useful model for understanding ecosystem-level consequences of plant invasion and restoration.

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## AN INTEGRATED RESPONSE TO A NEW COASTAL INVASION: MONITORING AND MANAGING *UNDARIA PINNATIFIDA* IN MONTEREY BAY

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### Oral Presentation

9:15 AM, Monday

The Asian kelp, *Undaria pinnatifida*, recognized as a marine threat because of its record of rapid spread and high abundance in invaded regions elsewhere, was first reported in 2001 from a site in the Monterey Bay region, California. Already widespread in other parts of the world, *U. pinnatifida* has recently appeared in various southern California harbors from Los Angeles to Santa Barbara. Because of its rapid population growth, high density, canopy-forming growth form and potential availability as a source of food and habitat for invertebrates, *U. pinnatifida* could have profound influences on the structure and function of our highly productive and species-rich coastal reef ecosystems. The population reported from Monterey Harbor is the northern-most known occurrence of the alga along coastal California. Regional agencies and researchers are collaborating to study: 1) the spatial extent of the invasion, 2) habitat associations, 3) seasonal dynamics of growth and reproduction, and 4) the costs/benefits of different potential eradication methods. This effort is also being used to create a regional management structure and decision-making process for rapid response to future coastal invasions.

Because the distribution of *U. pinnatifida* in central California is unknown, we are surveying in situ the four harbors in the Monterey Bay region and various adjacent natural sites along the open coast. To determine the phenology of the alga in its new environment (which can vary regionally), we use stratified random sampling to encompass all habitat types within each study site and across all seasons. Although eradication efforts rarely succeed, we will experimentally evaluate different methods of removal within the harbor. Concurrent with measuring the response of *U. pinnatifida* to eradication efforts, we will monitor community composition in each of the treatments, employing multivariate analysis to assess community-wide impacts of the eradication methods and the presence/absence of *U. pinnatifida* in experimental plots.

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## **ECONOMIC IMPACTS OF INVASIVE NONINDIGENOUS SPECIES IN CANADA: A CASE STUDY APPROACH**

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### **Oral Presentation**

12:15 PM, Wednesday

Introduction of invasive nonindigenous species is a leading cause of biodiversity change globally, and is a particularly acute problem in aquatic ecosystems. Nonindigenous species also pose risks to human health and to Canada's economy. In this report we detail the estimated economic cost of invasive nonindigenous species to the Canadian economy with case studies from three key sectors: agriculture, forestry and aquatic and coastal marine ecosystems. Economic damage associated with invasive nonindigenous species is widespread in each of these sectors, and affects virtually all regions of the country. Costs to Canadian agriculture for 6 selected invasive nonindigenous species amount to nearly \$273 million, though potential damage and control could range from \$5.3 to \$14.0 billion per annum. Annual potential damage and control costs in forestry amount to between \$7.7 and \$20.1 billion, while those in aquatic systems are from \$299 and \$776 million per annum from 8 and 4 surveyed invasive nonindigenous species, respectively. Some emergent sectors (e.g. aquaculture) have been harmed significantly by introduction of invasive nonindigenous species, while in other cases (e.g. zebra mussel infestations) costs are disseminated across a host of industries and resource users. As a resource-based economy, Canada can and is being significantly harmed by invasive nonindigenous species. However, in most cases it is virtually impossible to accurately determine direct or indirect damage caused by, or control costs associated with, invasive nonindigenous species. Lack of detailed studies has rendered difficult a comprehensive assessment of overall costs of invasive nonindigenous species to the country. Greater global trade, conducted with an increasing number of countries, will enhance opportunities for additional invasive nonindigenous species to invade the country and cause further damage to each of the sectors surveyed. At present, Canadian Food Inspection Agency surveillance programs examine only a small fraction (<2%) of products inbound to Canada for nonindigenous species. Furthermore, scant resources are presently dedicated to assessing threats posed by, and implementation of policies to prevent establishment of, new invasive nonindigenous species to Canada's forests, agricultural systems and Great Lakes and marine habitats. We propose that a national program is required to adequately identify and manage risks associated with undesirable nonindigenous species.

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# COMPLEX LIFE HISTORY AND THE DYNAMICS OF RANGE EXTENSION IN A NOVEL ENVIRONMENT: LESSONS FROM 5 YEARS OF OBSERVATIONS OF THE INVADING GASTROPOD *RAPANA VENOSA*

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## Oral Presentation

11:45 AM, Tuesday

Biological invasions often offer unique opportunities to examine fundamental paradigms in ecology. An example is the role of pelagic larvae in the maintenance of population structure of sessile invertebrates. Pelagic larvae offer sessile species the opportunity to exploit distant habitats and thereby insure species survival in the face of local extinction events. Examination of dispersal from a point source on a single generation basis in endemic species is confounded in that both immigration and emigration occur simultaneously. Further, in contiguous populations the effective distance over which genetic dispersal occurs generally cannot be discerned without extensive knowledge of the underlying genetic structure within the population. By contrast range expansion of an invading species in a novel receptor environment illustrates larval dispersal as a series of sequential emigrations in the absence of immigration. The end point of these emigrations is an expanding “front” of subsequent generations of adults. A time series of collections of the invading predatory gastropod, *Rapana venosa*, in the southern Chesapeake Bay is described for the period 1998–2002, that is the period since the initial report of the invasion. Over 4300 individual specimens, obtained predominantly from a fishery bounty program with over 100 active commercial participants, are described with respect to demographics by year and geographical source. Despite extensive larval culture data suggesting a capability for rapid range expansion and establishment throughout the lower Chesapeake Bay, the demographics indicate multiple size class (which we consider as multiple year classes and/or generations although precise age determination is a subject of continuing work) establishment within the 1998 range of collection, but only marginal range expansion since that time. These observations will be discussed in terms of possible spatial and temporal biases associated with fishery based bounty programs, estimated carrying capacity for the invading population within the described range of establishment, and knowledge of local circulation patterns with respect to larval dispersal.

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**THE USE OF MITOCHONDRIAL DNA TO INFER SCENARII ABOUT  
THE ORIGIN OF THE RECENT INVASION BY *OCINEBRELLUS INORNATUS*  
(RECLUZ 1851) IN FRANCE**

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**Oral Presentation**

1:45 PM, Monday

Since the beginning of the 20th century, the rate of introduction of foreign species has increased in the marine environment. Molecular genetics offers powerful tools to analyse the patterns and the processes associated with biological invasions. The Asian oyster drill, *Ocenebrellus inornatus*, is a marine gastropod recently introduced from Asia into both western America (around the 1920's) and France (around the 1990's). We addressed the question of whether or not genetics relationships exist between the *O. inornatus* populations from these two invaded regions with the native Asian population. A total of 78 individuals were collected from the south coast of Korea (native range), the Pacific coast of the United States (Samish Bay) and the French Atlantic coast (Marennes-Oléron Bay). Three mitochondrial DNA fragments (12S, 16S and COI) were sequenced for comparison. Our results showed a significant genetic differentiation exists between the Korean population and both the French and the American populations. A moderate decrease of the genetic diversity within the introduced populations, when compared to the diversity in the native population, conformed only slightly to the theoretical expectations. Moreover, no strong deviations from the equilibrium models were noted. These observations suggest that a large number of individuals from one or several sources were initially introduced into France. A strong genetic homogeneity was observed between the French and the American samples although a population structure was revealed in the French population from Marennes-Oléron Bay. Both our results and the dates of the first occurrence of the drills in France and in the United States suggest that the American population acted as one of the sources to France. Testing the hypothesis of a second introduction from Asia will require a more extensive study of drill populations from their native region.

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**THE ECOLOGY OF OVIGEROUS EUROPEAN GREEN CRAB,  
CARCINUS MAENAS (L.), AND IMPLICATIONS FOR CONTROL EFFORTS  
IN THE NORTHEASTERN PACIFIC**

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**Poster Presentation**

Monday

Efforts to eradicate nonindigenous species or control their spread may fail if management plans do not specifically focus on critical or susceptible life history stages of the target organism. The case of European green crab, *Carcinus maenas*, in the northeastern Pacific provides one such example. Current control strategies rely on baited traps which primarily capture male crabs, possibly because ovigerous (egg-bearing) females are less mobile and unresponsive to bait. Yet removing males is of little consequence in limiting populations since one male can mate with multiple females within a season and sperm storage by the latter may allow them to fertilize many broods from a single encounter. The targeted removal of ovigerous *C. maenas* may be an effective method for reducing propagule pressure but the lack of information regarding habitat use and behavior of female crabs has hindered efforts. We conducted intertidal surveys of ovigerous *C. maenas* in Tomales Bay, California, USA, in May/June 2001, and subsequent experiments were undertaken at Bodega Marine Laboratory, Bodega Bay, California, to investigate substrate preference and habitat competition with native brown rock crab, *Cancer antennarius*. Survey observations suggest that aggregations of ovigerous *C. maenas* occur under boulders or other epibenthic structure at +0.16 to +0.24 m MLLW. Ovigerous crabs also preferentially bury in sand substrate in the field and under laboratory conditions. Results of a habitat competition experiment and nighttime video observations indicate that *C. antennarius* may affect the distribution and habitat utilization of ovigerous *C. maenas* in some areas. Implications for monitoring and control efforts are discussed, as well as recommendations for future work.

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## AN EVALUATION OF THE IMPACTS OF THE CHINESE MITTEN CRAB ON THE BENTHIC COMMUNITY IN THE SACRAMENTO-SAN JOAQUIN DELTA

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### Oral Presentation

12:00 PM, Monday

The Chinese Mitten crab, *Eriocheir sinensis*, is among the more recent invaders to the San Francisco Estuary. Ecological impacts associated with this introduced species as well as basic biological information, are not well understood. The main objective of this study is to examine changes in invertebrate abundance and species composition in the benthic community as a result of predation by mitten crabs. To examine changes in the benthos an enclosure study was conducted from May to November 2001 and from June to September 2002.

The enclosure study consisted of three treatment types; (1) enclosures; (2) exclosures; and (3) non-treatment areas. Each month, six enclosures and six accompanying exclosures were paired and randomly placed within each study site. Each enclosure was stocked with 2 mitten crabs, predominantly juveniles measuring 25 to 45 mm CW. Each monthly trial lasted from 10 to 14 days. To measure differences in invertebrate abundance and composition between treatments a steel corer was used to collect samples. Core samples were taken from each enclosure, exclosure and from six randomly selected ("non-treatment") areas located in close proximity to the enclosures. All benthic invertebrates collected in the corer were identified to lowest possible taxon and enumerated. Juvenile crabs placed into the enclosures were retrieved at the end of each trial and frozen for later analysis of stomach contents. Analysis of stomach contents from retrieved crabs will be analyzed for frequency of animal and plant tissues present. To detect the quantity of submerged aquatic vegetation consumed by crabs in the enclosures an estimation of the canopy cover of aquatic vegetation present in the enclosures and exclosures was made before and after each trial period.

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## WESTWARD HO': ZEBRA MUSSELS ON THE MOVE

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### Poster Presentation

Monday

This poster presentation is an introduction to the CA Department of Water Resources/CALFED Zebra Mussel Detection and Outreach Program. Information provided by this poster presentation includes a summary of the Program's goals, basic background information about zebra mussels, *Dreissena polymorpha*, and a description of the volunteer monitoring program for early detection of mussels in California.

The Zebra Mussel Detection and Outreach Program is a multi-year project funded by DWR and CALFED. The goals of this program are to establish a means to: 1) educate the general public about zebra mussels, 2) conduct early detection monitoring in the field, 3) set-up a centralized reporting system by which detection of zebra mussels can be reported and conveyed to all interested parties, 4) conduct a risk assessment of waterbodies in the central valley watershed, and 5) establish a rapid response plan for zebra mussel introduction in California. The objective of this poster presentation is to provide information about zebra mussels that is relevant to the scientific community as well as the general public of California. This presentation includes basic information on zebra mussel biology, origins, means by which these mussels spread from one water body to another and methods for preventing the spread of mussels by recreational vessels. Impacts to the aquatic ecosystem, water conveyance and treatment facilities and recreational activities are also discussed. Lastly, we provide a description of the volunteer monitoring program that will be developed and used for the early detection of zebra mussels in California. Agency contact information is provided for persons interested in becoming volunteer monitors.

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## SUB-LETHAL FISH PREDATION ON ONE NATIVE AND TWO NON-NATIVE BIVALVES

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### Poster Presentation

Monday

Predation may help regulate the distribution of non-native species. I examined the predatory habits of a siphon-nipping fish (*Leptocottus armatus*, the Pacific staghorn sculpin) on one native bivalve (*Protothaca staminea*) and two non-native bivalve species (*Venerupis phillippinarum*, *Nuttallia obscurata*) found in the intertidal zone of the San Juan Islands, WA, USA. I collected fish in a field survey and examined their stomach contents to ensure this type of predation occurs locally. Bivalve siphons were found in 25-31% of inspected stomachs, accounting for 1-2% of total stomach content weight. Siphons were in various states of digestion, therefore I was unable to positively identify clam species.

To determine if *L. armatus* exhibits a preference for one species of clam over another, I conducted a prey choice experiment in the laboratory. The results allowed me to quantify the number of clams preyed upon, compare the frequency of predation between clam species, and examine clam burial depth as a defense mechanism. Results showed that *L. armatus* includes all clams as prey and exhibits no preference for one species over another (*P. staminea*: 10% of clams exposed were nipped, *V. phillippinarum*: 12%, *N. obscurata*: 13%). Burial depth between species was significantly different (*P. staminea*: 3.85cm  $\pm$ 1.7, *V. phillippinarum*: 0.98cm  $\pm$ 0.92, *N. obscurata*: 5.59cm  $\pm$ 1.8). However, because predation rates were identical, burial depth apparently has little influence on siphon-nipping.

Despite equal fish selectivity in the lab, *N. obscurata* in practice likely enjoys reduced predation rates in the field compared to *P. staminea* and *V. phillippinarum*. Specifically, *N. obscurata* occupies a higher zone in the intertidal (+1.5m MLLW) than *P. staminea* and *V. phillippinarum* (+1.0m MLLW) and therefore is exposed less to fish predators that are physiologically constrained by the tide. *N. obscurata*'s deeper burial depth would seemingly allow it to avoid excavating crab predators more effectively as well. These factors may contribute to *N. obscurata*'s overall success in the intertidal.

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## INVASION MODELS AND APPROACHES: PREDICTING INVASION SUCCESS OF MARINE SPECIES

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### Oral Presentation

8:45 AM, Wednesday

The historic, mass transport of the eastern oyster (*Crassostrea virginica*) from the Atlantic coast to San Francisco Bay and other West Coast embayments provides a rare opportunity to explore and predict characteristics associated with invasion success of marine species. Organisms transferred with oysters comprise a well-defined species pool emanating from a single source region and arriving to a single recipient region. By employing key characteristics of molluscan oyster-associates (e.g., biogeography, life history, and habitat attributes) we discriminated statistically between successful and failed invaders. Linear discriminant analysis identifies some species that cluster tightly with successful invaders in our model, but which have failed to invade themselves. Should these species be considered incipient invaders? At least two such species (*Littorina saxatilis* and *Littorina littorea*) have invaded San Francisco Bay recently, probably with the brown alga (*Ascophyllum nodosum*) that is used to pack live lobsters and bait worms from New England. The discovery of thriving *Ascophyllum nodosum* colonies in San Francisco Bay in 2002 indicates that the vector itself has become an invader. Algal packing materials and oysters are analogous vectors - both are transfers of complex habitats and associated biota. Although smaller in scale, habitat transfers operate more efficiently than shipping related vectors (i.e. ballast water or hull fouling) for three reasons. First, success in locating an appropriate habitat is not an issue. Second, post-larval forms are delivered (per shipment) to the same locality and may remain in close proximity. This may serve to reduce dispersion, promoting a critical population size that facilitates mate location and successful reproduction. Third, for oysters and algal packing material, transport conditions are designed to maximize survivorship of target species and confer high survivorship to associated species. Habitat transfer vectors are excellent systems to investigate invasion processes but should also be among the easiest vectors to manage.

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## ASSESSMENT OF INVASIVE SPECIES IN DELAWARE'S INLAND BAYS AND MARYLAND'S COASTAL BAYS

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### Poster Presentation

Tuesday

Using rapid survey techniques, we have initiated an assessment of the invasive species in the coastal bays along the Atlantic coastline of Delaware and Maryland, from Rehoboth Bay south to Chincoteague Bay. These back-barrier bays share many common characteristics such as shallow depth, sandy to muddy bottoms, little natural hard substrate, and fringing salt marsh. Threats to ecosystem health include: nutrient enrichment and eutrophication, low oxygen events, harmful algal blooms, high summertime visitor usage, and shoreline development. Despite the known presence of several invasive species (e.g., Asian shore crab, green crab and green fleece seaweed), there has been no comprehensive survey of the type necessary to form the scientific basis for invasive species management plans. We anticipate that these bays form a continuum in water quality, watershed characteristics, and human impact and disturbance that may be related to their susceptibility to invasions. This presentation will summarize the results of our survey and assessment at mid-project.

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## DEVELOPING STRATEGIES TO MANAGE AQUATIC INVASIVE SPECIES

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### Oral Presentation

2:45 PM, Wednesday

A complex system of local, state and federal jurisdictions govern within the Chesapeake Bay drainage basin. These jurisdictions cooperate on efforts to restore and protect the Chesapeake Bay through a regional partnership. The most recent agreement by these partners, Chesapeake 2000, calls for the development and implementation of management plans for invasive species deemed problematic to the Bay's ecosystem. In response to this agreement, the Chesapeake Bay jurisdictions identified six species (*Phragmites australis*; *Lythrum salicaria*; *Trapa natans*; *Cygnus olor*; *Myocastor coypus*; *Dreissena polymorpha*) that cause, or have the potential to cause, significant degradation to the Bay's aquatic ecosystem. A workshop held in May, 2002 produced consensus frameworks that will be used to develop management plans for the six species. This talk will highlight important aspects of the workshop and the consensus frameworks.

Past attempts at designing management plans involved limited numbers of stakeholders and generally considered single species. This workshop brought together participants who represented regional jurisdictions and varied interests to discuss concurrently the development of management plans for multiple aquatic invasive species. The strength of such an approach is that it brings together a variety of specialists and provides an opportunity for discussions – across disciplines, jurisdictions and agencies – on ways to more optimally share limited resources for managing various invasive species within a large watershed.

The workshop completed management frameworks for each of the six species and identified areas of management overlap. Recurring management themes included the necessity of increasing public awareness, strengthening monitoring and building strong public-industry-government partnerships. The ultimate success of the workshop will now depend on the actions taken to finalize and implement these consensus frameworks for developing species management plans. The workshop design and the jurisdictions' implementation strategy provide a valuable model for developing future regional strategies to manage multiple aquatic invasive species.

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## MANUAL REMOVAL AND RE-GROWTH OF THE ALIEN INVASIVE ALGA (*GRACILARIA SALICORNIA*), ON VARIOUS REEF SUBSTRATES IN WAIKIKI, OAHU

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### Poster Presentation

Tuesday

The tropical red alga (*Gracilaria salicornia*) was introduced to reefs fronting Waikiki, Hawaii in 1971 for experimental aquaculture and has since become invasive. *G. salicornia* has now spread throughout much of Waikiki and adjacent reef areas where it is now an ecological dominant. Because *G. salicornia* appears to be displacing native species, state and federal managers have generated an interest in developing mitigation strategies to control its abundance. The goals of this study were to assess the feasibility of manual removal by determining the man-hours required to clear plots of differing cover and habitat type. Re-growth of the invader was monitored in permanently established plots for 4 months following removal to determine the effectiveness of clearing.

Initial percent cover, manual removal time and biomass (wet weights) were recorded for fifteen  $\frac{1}{4}$  m<sup>2</sup> plots along three 30 m transects. Reef substrate types were categorized and compared with man-hours required for removal and biomass collected. Re-growth was determined by surveying cleared plots after removal and then monthly for 4 months. Average percent cover of *G. salicornia* before removal was 47.2% ( $\pm$  20.6% SD). Average man-hours for removal were 3.75 hours/quadrat ( $\pm$  2.25 h/q SD). Mean biomass collected was 5385.6 g/m<sup>2</sup> ( $\pm$  3408.0 g/m<sup>2</sup> SD). Plots with higher biodiversity and rubble type substrates required the most man-hours for removal. Re-growth data showed that *G. salicornia* returned to 64.9% of its initial percent cover 4 months following removal.

Data obtained in this study indicates that large-scale manual removal of *G. salicornia* would require immense resources in terms of man-hours and economic investments. Future research should investigate other options for control such as enhancement of native herbivore populations.

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## STATE OF HAWAII-BALLAST WATER AND HULL FOULING ALIEN AQUATIC ORGANISM MANAGEMENT PROGRAM

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### Oral Presentation

2:15 PM, Tuesday

The State of Hawaii is developing a management program for preventing the introduction of alien aquatic organisms via ballast water discharge and sediment, and hull fouling. In 2000, the State legislature designated the Department of Land and Natural Resources (DLNR) the lead agency in the prevention and carrying out the destruction of the alien aquatic organisms coming to Hawaiian waters via these vectors.

There are 4 components for this management program. They are:

- 1) An interagency task force,
- 2) Development of High Risk Vessels (HRV) protocols and procedures,
- 3) A rapid response team,
- 4) Development of outreach material.

An interagency task force has been established from State and Federal agencies, the shipping industry, and the scientific community. Their purpose is as an advisory group and focus on the issues, problems, and concerns of ballast water exchange, ballast sediment, and hull fouling, and then provide a list of recommendations to DLNR, for their consideration for the development of this management program.

The next component is the development of high-risk vessels (HRV) protocols and procedures to notify the DLNR whenever a HRV comes into Hawaiian waters. A HRV can be any recreational and commercial vessel, and floating structures, such as barges, dry docks, drilling rigs, and cranes, which have spent extended periods of time tied up in out-of-state ports.

Another component in this program to resolve the HRV issue is a rapid response team made up of Task Force members that would be called in emergencies to investigate any HRV that enters into Hawaiian waters. This team would then determine if the HRV is allowed to port in Hawaiian waters.

The final component in the management program is the creation of outreach material to educate the general public on the impacts of alien aquatic organisms and the vectors that spread these organisms.

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## CAULERPA TAXIFOLIA IN AUSTRALIA: A GROWING PROBLEM

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### Oral Presentation

9:45 AM, Monday

*Caulerpa taxifolia* is a high profile introduction to the Mediterranean Sea and California. It is native to sub-tropical regions of Australia, however, during 200-01 six locations with abundant *C. taxifolia* were discovered in temperate waters around Sydney. In 2002, two new incursions of *C. taxifolia* have been found in South Australia.

Introductions to New South Wales and South Australia are not considered likely to be natural range expansions as southern distribution limits for *C. taxifolia* are recorded at Moreton Bay, southern Queensland and Lord Howe Island.

Management of these introductions is complex as the aquarium-Mediterranean strain of *C. taxifolia* is included on the interim species list that will trigger a marine pest incursion emergency response in Australia. This determines access to Commonwealth and state government funds for eradication. As *Caulerpa* is native to Australia, it is essential to identify new incursions as a domestic translocation or an introduction of the aquarium-Mediterranean strain from overseas.

With the discovery of new incursions in South Australia the ability to identify *C. taxifolia* and assign source locations to incursions quickly, is essential for a management response to this invasive algae. We provide an overview of strain identification using morphology and molecular techniques. We also discuss a decision response framework for managing future incursions.

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## DINOFLAGELLATES AS BIOMONITORS OF BALLAST WATER TREATMENT EFFICIENCY

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### Oral Presentation

5:30 PM, Monday

Since international research efforts are focused on development of a variety of ballast water treatment techniques, it is vital to evaluate the efficiency of the treatment in terms of removal and /or inactivation of organisms in seawater. Although it is a difficult task to select one specific organism as a surrogate to study the efficiency of treatment, this research focused on the dinoflagellate species, *Scrippsiella* sp., as a surrogate. This paper discusses the selection process of the dinoflagellate as surrogate organism and its application in evaluating the efficiency of ballast water treatment. Also, the paper discusses in detail the microbiological techniques involved in culturing of *Scrippsiella* sp., cyst formation (Hyponozygote) and regeneration of the cyst into a cell, which could possibly be applied in the evaluation of ballast water secondary treatment. All the culture studies were carried out in a temperature-light intensity controlled room. The room temperature was maintained at 26°C and the upper limit cutoff was installed and set at 30°C to switch off the lights if the temperature in the room significantly exceeded the set temperature of 26°C. A timer controlled all lights on a 12-12 hour light-dark cycle. The microscopic study and manual counting were used to study the morphology and the number of cells and/or cysts of the dinoflagellate. The growth rate of *Scrippsiella* sp. is 0.18 – 0.24 divisions per day<sup>-1</sup> and its cyst formation rate is 0.05 cysts per day<sup>-1</sup>.

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## MODIFICATION OF TIDAL FLAT AND *SALICORNIA* MARSH ANIMAL COMMUNITIES BY INVASION OF A *SPARTINA* HYBRID IN SAN FRANCISCO BAY

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### Oral Presentation

11:15 AM, Monday

Cordgrasses can be highly aggressive invaders that significantly alter both the physical structure and biological composition of tidal marshes, mudflats, and creeks. In San Francisco Bay, *Spartina alterniflora* has hybridized extensively with the Pacific native *S. foliosa*; the result is a more vigorous plant able to invade open tidal flats as well as environments naturally dominated by *Salicornia virginica*. Little is known about the extent to which the replacement of open tidal flats and *Salicornia*-dominated habitats by the *Spartina* hybrid affects sediment properties and benthic animal communities. Using a mensurative approach, we compared environmental conditions and biota in *Spartina* hybrid-invaded and uninvaded patches in three wetland habitats of San Francisco bay: San Mateo, San Lorenzo and Alameda (Elsie Roemer). Our null hypothesis was that the *Spartina* hybrid invasion has similar consequences for benthic community and ecosystem structure in different systems. In San Mateo, where the hybrid is invading *Salicornia* habitat, the effects are limited, probably because of a more complex interplay between plant interactions (competition) and physical conditions. In San Lorenzo and Alameda (Elsie Roemer) where the hybrid is invading tidal flat habitat, modification of physical conditions is greater and the biotic consequences are stronger. Transplant experiments that moved infauna from tidal flat to hybrid-vegetated habitats suggests that domination by subsurface-deposit feeders in invaded patches may be related to superior survival. There was reduced survival of selected tidal flat species such as clams and amphipods. Overall, these studies document that the invasion by the *Spartina* hybrid can alter the face of benthic communities in central San Francisco Bay but the nature and extent will vary among local systems.

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## EXOTIC SPECIES INTRODUCTION CONCERNS IN ARCTIC WATERS

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### Poster Presentation

Tuesday

Various reports have indicated a number of physical and biological changes in Arctic waters that may be associated with global warming. Exotic species have not been an important issue in this region because the probability for introduction is low, and the receiving environment is hostile. Except for Port Valdez, AK, few if any surveys have been made to identify species exotic to this region. This task is made even more difficult because of limited zoogeographic information of the species present. Increased annual mean temperatures have raised the risk of exotic species introduction to eastern Canadian Arctic waters because of increasing vessel traffic. A recent U.S. Navy Study suggested shipping in this region could sharply increase within 10-20 years. The Port of Churchill, on Hudson Bay, has been a seasonal port for a number of years with a navigation season of about 2 months. This route is more cost effective in shipping bulk goods from western and central Canada, than the usually route through the Great Lakes. It is highly probable that this will become a major deepwater port for bulk goods over the next several decades because the length of the navigation season continues to increase, and port storage and docking facilities, and rail transit to the port have recently be upgraded. Historical information has indicated nearly all vessels enter the port in ballast, and depart loaded of cargo. The likely shift of shipping bulk goods through Churchill rather than the traditional route through the Great Lakes – St. Lawrence Seaway may substantially increase the risk of exotic species introductions to Arctic waters.

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## **SPECIES CHARACTERS - ARE THERE ANY GENERAL PATTERNS IN SUCCESSFULLY ESTABLISHED MARINE MACROALGAL INTRODUCTIONS?**

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### **Poster Presentation**

Monday

Within the new Swedish research programme AquAliens, financed by the Swedish EPA, we will, amongst others, analyse patterns of species characters for various types of introduced organisms having established successfully. Whenever possible also species having failed to establish will be scrutinized, if it is not obviously due to climatic factors or salinity differences. Our project focuses on marine macroalgae.

Data on a range of species characters for the slightly more than 100 marine macroalgae introduced in Europe have been collected from a wide source of literature. Special emphasis has been given to searching for patterns in successfully established macroalgae for:

- 1) characters of importance for dispersal (e.g. floating, entangling, growth on secondary substrate),
- 2) life history strategies, size and fecundity,
- 3) habitat occupied (incl. tolerance to pollution),
- 4) vegetative dispersal and growth of loose-lying individuals,
- 5) ranges of abiotic factors tolerated (above all salinity, temperature, desiccation, darkness),
- 6) grazer resistance and secondary metabolites.

Data on quantitative ranking of such characters will be presented and compared to reports of species' invasiveness. These results will later constitute a basis for estimates of impact on biodiversity and ecosystem functions, as well as for the type of coastal waters most likely affected.

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# POPULATION DYNAMICS AND ECOLOGICAL IMPACTS OF THE PONTO-CASPIAN PREDATORY CLADOCERAN (*CERCOPAGIS PENGOI*) IN THE BALTIC SEA

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## Oral Presentation

4:45 PM, Monday

Population dynamics of *Cercopagis pengoi* (Ostroumov 1891) has been studied in the long-term zooplankton monitoring station in the Gulf of Riga (NE Baltic Sea) on weekly basis during the ice-free period since the invasion in 1992. Density of *Cercopagis* population has increased exponentially during the first ten years of invasion. The seasonal population development followed the course of water temperature; the highest population abundance was recorded in the first week of August. The duration of presence of *Cercopagis* in the zooplankton community tended to increase over the years. This was achieved by shifting its population development to earlier time, similar to the pattern observed for the probable prey of *Cercopagis* in spring and early summer - *Eurytemora*. After the invasion of *Cercopagis*, the annual mean abundance of *Bosmina* was significantly lower than during the pre-invasion time, probably due to direct predation. Although population densities of other mesozooplankton taxa did not follow this pattern at the multi-annual scale, development of some of them (e.g., copepod nauplii and *Acartia*) has substantially changed at the seasonal scale. The annual mean share of *Cercopagis* remained low in the diet of most abundant planktivorous fish species. However, the fish may rely up to 100% on the alien species as an energy source in the warm season. The *Cercopagis* invasion has increased species diversity of the pelagic fauna and, consequently, the overall stability of the ecosystem by incorporating an additional element to the trophic link of carnivores in the pelagic food-web. This invasion has additionally resulted in the enhancement of relative importance of the warm-water planktonic invertebrates in the energy flow to cold-water benthic-pelagic fish communities. This study suggests that invasion of *Cercopagis* has substantially changed dynamics of other zooplankton taxa, the species is utilised by higher trophic levels and dietary overlap between *Cercopagis* and fish larvae and planktivorous fish (especially for copepod nauplii, *Eurytemora* and *Acartia*) may occur.

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## STUDY OF INTERACTIONS BETWEEN AN INTRODUCED SNAPPER AND NATIVE SNAPPERS IN A HAWAIIAN FISHERY

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### Oral Presentation

9:15 AM, Tuesday

We performed a study in deep waters off the coasts of Hawaii to search for evidence of interactions between native deep-water snappers and the blueline snapper or taape (*Lutjanus kasmira*), which was intentionally introduced to Hawaii from French Polynesia in the 1950s. The taape had quickly produced large populations and expanded throughout the archipelago. Concern had been expressed that it might be producing negative effects on populations of native deep-water snappers in the valuable handline fishery.

We collected specimens of the taape and all the major native fishery species using commercial methods, and collected data on catch, effort, and characteristics of the fishing process, and we examined gut contents for evidence of predation or diet overlap among the snappers. Fish density and habitat use were studied on dives with a manned submersible and remotely operated vehicle. Existing records from previous deep dives and research catch and effort were examined.

Taape were caught in shallower water depths (<150 m) than all native species except one, and on different diel feeding schedules. They fed lower in the water column than the two native species with most similar ranges of water depths, and had very different diets from those species. Their diets were also readily separated by overlap analysis from the other, bottom-living native snappers. No clear evidence was found of predation either by taape on native species or vice versa. Underwater observations confirmed minimum spatial (especially depth) overlap of taape with native snappers and no evidence of aggression. Overall, the results do not imply strong negative effects of taape on adults of native fishery species in these habitats. The study does not address the potential for interactions of taape with young stages of the native snappers or with native species in shallow-water coastal habitats.

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## MOLECULAR DETECTION TECHNIQUES FOR MONITORING THREE KEY PEST SPECIES IN BALLAST WATER SAMPLES

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### Oral Presentation

2:30 PM, Monday

At any point in time there are an estimated 10,000 marine species being transported around the world in ballast water. Numerous nonindigenous pest species have apparently been established through this transport. The seastar, *Asterias amurensis*, the Pacific oyster, *Crassostrea gigas*, and the dinoflagellate, *Gymnodinium catenatum*, are three such species, that have been categorized as among the top 12 introduced marine pests into Australian waters, that pose the risk of spreading to non-invaded ports/ locations through ballast transport. Identification of planktonic forms by morphological examination is not practical, but unequivocal identification is critical to understand their distribution, ecology, transport and the risks posed to non-invaded environments. To this end, and to assist in routine and reliable monitoring of ships ballast, we have developed specific nested PCR-based tests for detection of the three species in environmental and ballast water samples. Currently the probes are being used to validate type II errors associated with a decision support system (DSS) being trialed as part of national demonstration project involving port of Hasting in southeast Australia.

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## EFFECT OF ULTRAVIOLET LIGHT TREATMENT ON HETEROTROPHIC MARINE BACTERIA FROM PUGET SOUND, WASHINGTON

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### Poster Presentation

Tuesday

Investigators are proposing and testing several technologies that could be used to inactivate organisms present in ballast water. One of the proposed technologies is ultraviolet light (UV). To test the effectiveness of UV, we conducted small-scale experiments using Puget Sound water at the USGS Marine Laboratory at Marrowstone, Washington. These experiments were done using two systems, a capillary flow reactor and a collimated beam apparatus. Both systems provide a uniform dose of UV radiation to the sample. During these tests, we were able to determine not only how different levels of UV dosage initially affected a sample of heterotrophic marine bacteria, but also how well the treated bacteria were able to grow following a 48-hour incubation period. Results from these experiments showed a 10,000-fold reduction in culturable bacteria following a UV radiation dose of 75 mJ cm<sup>-2</sup>. This indicated either complete inactivation of bacterial reproductive ability, or at least a significant period during which DNA damage inhibited reproductive function. However, a 100 to 1,000-fold rise in culturable bacteria was observed following the 48-hour incubation (grow back) period, showing the ability of some bacteria to reproduce. Using fatty acid analysis we determined the relatedness among bacterial strains isolated from these experiments. In addition, we established UV dose response curves for three of the more UV radiation resistant bacterial isolates. These curves indicated that survival of bacteria following treatment may depend more on extraneous factors than resistance to UV light itself. The genes for the 16S rRNA of these three isolates was sequenced to compare the phylogenetics of these isolates to known species. While UV radiation appears effective in lowering the population of culturable marine bacteria in seawater, the issues of bacterial growth following treatment and the possible selection of UV-resistant microorganisms needs to be addressed.

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## **OZONE TREATMENT OF SEAWATER MESOCOSM EXPERIMENTS: BACTERIAL COMMUNITY ENUMERATION WITH FLOW CYTOMETRY**

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### **Poster Presentation**

Tuesday

Ozone has been used as a treatment for the inactivation and removal of small organisms, such as bacteria, in freshwater and seawater. Some of the current and potential uses of ozone in seawater include aquaculture, water purification, particle reduction, and the treatment of ballast water. Analyses of such treatments require quantification of reduction of microbial populations, including bacteria and phytoplankton. Cultural methods, such as inoculating agar plate media with environmental samples, do not provide the total number of organisms present in a community. Microbial populations may also exist in a viable but nonculturable state. Flow cytometry method (FCM) is an enumeration technique, which increases the precision of total bacterial counts compared to cultural methods, and is a faster analysis that has less enumeration bias compared to epifluorescent microscopy. Mesocosm experiments were conducted at the USGS Marine Laboratory at Marrowstone Island, Washington. Seawater mesocosms were created to determine the concentration of ozone and its by-products necessary for removal of organisms equal to or greater than reported ballast water exchange. Our FCM protocols included fixing the sample with 1% paraformaldehyde for 15 min with storage at  $-20^{\circ}\text{C}$ . SYBR II (Molecular Probes Inc.) dye was used to stain microorganisms at a 1:1000 concentration. Samples were analyzed by a FacScan cytometer for one-minute intervals that represented a 60ul aliquot. A suspension of 0.93um red fluorescent microspheres were added for an additional internal reference and size verification. A typical 60ul sample of seawater showed initial counts well above 3,000 for high DNA (HDNA) density particles and over 1,000 for low DNA (LDNA) density particles. Ozonation of seawater can be assessed by measuring the total residual oxidants (TRO). When concentrations of TRO were as low as 1.0 mg/L the levels of microorganisms, as determined by using heterotrophic plate count and FCM, were reduced by over 99.9%.

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## INTERJURISDICTIONAL RESPONSES TO AQUATIC NUISANCE SPECIES IN THE PACIFIC NORTHWEST

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### Oral Presentation

4:00 PM, Monday

Authorized by Congress in 1947, the Pacific States Marine Fisheries Commission (PSMFC) is dedicated to resolving fishery issues. Representing California, Oregon, Washington, Idaho, and Alaska. The PSMFC works closely with the Center for Lakes and Reservoirs (CLR) at Portland State University on aquatic nuisance species (ANS) management.

The objective of the PSMFC ANS Program is to prevent harm from ANS species to important commercial and recreational fisheries and the ecosystems upon which these fish depend. Program emphasis is on outreach and education to appropriate user groups, assisting states in the region develop ANS management plans, and funding and coordinating monitoring of species of concern.

Currently, the PSMFC program funds are directed at four species: Zebra mussel (*Dreissena polymorpha*), Atlantic salmon (*Salmo salar*), European green crab (*Carcinus maenas*) and Mitten crab (*Eriocheir* spp). The CLR program includes research on these species and on freshwater aquatic weeds, ANS surveys, management planning for *Spartina* in Oregon estuaries, research on ballast water introductions of ANS, and implementation of the Oregon Aquatic Nuisance Species Management Plan.

The debate about aquaculture in the nearshore marine environment on the West Coast has mostly focused on Atlantic salmon. Concerns regarding Atlantic salmon on wild salmon stocks include disease transfer, pollution from net pen facilities, and ecological impacts from escaped salmon. The Alaska Department of Fish and Game and Washington Department of Fish and Wildlife will be using program funds in 2003 to monitor for presence/absence of Atlantic salmon in streams.

PSMFC is funding research to determine abundance and distribution of European green crab and mitten crab in selected West Coast locations, and to develop a model that will provide a basis to predict the potential range and population size for mitten crabs in these specific estuaries.

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## USE OF INCUBATOR-EMERGENCE TRAPS FOR HATCHING STUDIES IN BALLAST TANKS

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### **Oral Presentation**

12:00 PM, Wednesday

Sediments that accumulate in ballast tanks of transoceanic vessels have been shown to contain varying concentrations of resting stages (eggs, cysts, spores) of invertebrates and phytoplankton. Laboratory experiments have been successful in stimulating hatching under well-controlled optimized conditions, indicating a potential risk for invasion by these dormant stages. Whether such hatching takes place in ballast tanks under regular operating conditions is an important question, but not easily determined. Ballast tanks are not routinely or readily accessible, and sampling is usually restricted to one or two manhole hatches, or vent pipes, both of which are problematic for experimental purposes. Identifying organisms that may have hatched in situ against the background of organisms brought in with ballast water can be particularly difficult. Emergence traps have been routinely and successfully used in biological studies in many aquatic environments. A simple and low-cost incubator-emergence trap has been designed to conduct hatching experiments in operating ballast tanks on commercial vessels. Several experimental designs are possible with these traps. One field test was conducted during 2002 and several more are planned during 2003.

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## DATABASE OF THE NONINDIGENOUS SPECIES IN THE ESTUARIES OF CALIFORNIA, OREGON, AND WASHINGTON

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### Poster Presentation

Tuesday

The number and composition of the native and nonindigenous species is a key component in establishing baselines, conducting invasive species risk assessments, and setting regional prioritizations. The problem for both managers and researchers is that this information is scattered in the peer reviewed literature, gray literature, and various databases. With support from the Western Regional Panel of the Aquatic Nuisance Species Task Force (ANSTF), we have initiated a project to summarize information on species composition of the estuaries of California, Oregon, and Washington. Because of the potential transport of nonindigenous species within a water body, estuarine systems are classified as “independent”, those with a self contained water mass and a direct connection to the ocean, or “embedded” which are sub-estuaries or tributaries contained within a larger water body. In the three states, 135 independent estuaries and 271 embedded estuaries have been categorized and georeferenced. These estuaries range in size from 0.0142 km<sup>2</sup> to over 6000 km<sup>2</sup> for Puget Sound. When biological information is available for an estuary, we are compiling a species list as well as classifying the species as native, nonindigenous, cryptogenic, or indeterminate based on the literature. The primary focus will be on benthic invertebrates and fishes. Various physical attributes are also being summarized, including estuarine area, watershed locale, latitude/longitude, climate, and salinity when georeferenced data are available. The information will be captured in a stand alone Access database, which will present the results in standardized forms as well as allowing custom queries and reports. A prototype of the database has been developed using the 1999 EMAP survey of Pacific coast estuaries and contains information on 867 benthic species from 90 estuaries. To add to the database, the authors are seeking sources listing species composition in Pacific coast estuaries, particularly in the smaller systems.

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## TROPHIC ECOLOGY OF THE CHINESE MITTEN CRAB IN THE SAN FRANCISCO ESTUARY: IMPLICATIONS FOR AQUATIC FOOD WEBS

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### Oral Presentation

11:45 AM, Monday

Within the past decade, the non-native Chinese mitten crab has become firmly established in the San Francisco Estuary. The crab's complex life cycle includes migration over several kilometers of freshwater and estuarine systems, generating concern for its impacts over a wide variety of aquatic habitats. The mitten crab is known to be omnivorous, but its trophic ecology in the context of its new environment is poorly understood. Little is known about how impacts vary with habitat and the crab's development. We are using three complementary techniques to study the trophic ecology of the mitten crab: 1) gut content analyses; 2) controlled mesocosm experiments; and 3) carbon and nitrogen stable isotope analyses. Each of these techniques provides insights to the trophic ecology of this non-native species. Gut content analyses support the idea that this crab is omnivorous, feeding on a wide variety of detrital, algal and invertebrate matter, and also suggest dietary differences among populations of the crab throughout the Estuary. In mesocosm experiments, the crab decreased the abundance of a wide variety of prey items including the invasive clam (*Corbicula*) and other slow-moving invertebrates as well as macrophytes, algae and detritus. Stable isotope results suggest that, while the crab may be omnivorous, some plant materials including algae and detritus may not be as energetically important for the crab. The benthic impacts of this species were also compared and contrasted with those of the co-occurring, non-native freshwater crayfish (*Procambarus clarkii*). These results support the concern that the Chinese mitten crab is negatively impacting the estuarine and freshwater food webs of the San Francisco Estuary.

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## HINDCASTING INVASION IMPACT BASED ON SPECIES DEMOGRAPHY

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### Oral Presentation

11:00 AM, Monday

Invasion theory suggests that the risk of successful, high-impact invasion is likely to increase with a species' intrinsic population growth rate. We tested this theory by comparing demographic parameters of two introduced oyster drills (predatory gastropods) that vary in their documented impacts. *Urosalpinx cinerea* was imported to Willapa Bay, Washington with Virginia oysters before 1920 and remains generally restricted to southern parts of the bay. *Ceratostoma (Ocinebrina) inornatum* arrived with oyster seed from Japan about 1960 and has since required expensive manual control and caused abandonment of some oyster growing areas. Both drills undergo direct development and therefore spread slowly on their own, but they readily hitchhike on oysters transferred within the bay. We used laboratory observations and field mark-recapture techniques to determine growth, survival, and fecundity of each species. Both species suffered high mortality rates (to 20%/mo in summer) even at adult sizes. However, *C. inornatum* grew larger, had an earlier reproductive season, and produced more conchs per capsule than *U. cinerea*. In this case, the species with higher population growth rate also had higher reported economic impacts. This pattern may exist because of the overlap between the distribution of *C. inornatum* and current aquaculture locations. From parallel studies on density and per capita impact (feeding rate), we expect both species to have high ecological impacts within the areas where they have become abundant. Indeed, the local ecological impacts of these introduced drills are likely to be more similar than either demography or current management responses would suggest.

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## DAYTIME HABITAT USE PATTERNS AND THE SPECTRE OF COMPETITION FOR SPACE AMONG DEMERSAL REEF FISHES

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### Poster Presentation

Tuesday

Between 1955 and 1961, approximately 3,200 bluestripe snapper (*Lutjanus kasmira*, Family: Lutjanidae) were introduced to Oahu, Hawaii from French Polynesia. These fish adapted well to their new ecosystem and became abundant throughout the Hawaiian Archipelago. Despite their abundance and availability to fishers, initial hopes that *L. kasmira* would become a valuable food resource species have not been realized. Also, it has been suggested that these fish may adversely impact populations of native fishery species through competition for spatial or dietary resources, or through predation on young fish by adult snappers. We are conducting a series of investigations to assess whether such ecological relationships are likely to exist and impact populations of native fishery species. The current stage of our investigation addresses habitat overlap and spatial competition between *L. kasmira* and shallow-water reef fish. Researchers have gathered data on the habitat use patterns of *L. kasmira* and several reef fish species by conducting transect surveys on and off the reef. We found that the habitat use patterns of *L. kasmira* and the yellowtail goatfish (*Mulloidichthys vanicolensis*, Family: Mullidae) were most similar. Both species were primarily found low in the water column and were closely associated with areas of vertical relief. To more closely investigate this similarity, divers recorded the height above the substrate of individual *L. kasmira* and *M. vanicolensis* in the presence and absence of each other. Analysis of these data indicated that *M. vanicolensis* was found further from the substrate when *L. kasmira* was present, but that *L. kasmira* was not similarly affected by *M. vanicolensis*. This finding may indicate asymmetrical competition for sheltering space on the reef, in which the dominant *L. kasmira* displaces *M. vanicolensis* into the water column and away from the relative protection of the reef, which potentially increases its vulnerability to predators and fishers.

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## THE IMPACT OF INVASIVE ALGAE ON BIODIVERSITY AND CORAL COVER IN HAWAII

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### Oral Presentation

9:00 AM, Tuesday

The introduction of invasive species is often considered to be one the largest threats to global biodiversity in both terrestrial and marine ecosystems. However, remarkably few examples exist where invaders have been shown to cause significant negative impacts in tropical coral reef ecosystems. In the Hawaiian Islands, several species of macroalgae have been introduced (both intentionally and un-intentionally) since the mid 1950's. Currently five of these species have become ecological dominants in various habitats and appear to be displacing native flora and fauna. In particular, two mat-forming red algae (*Gracilaria salicornia* and *Kappaphycus alvarezii*), introduced to Waikiki and Kane'ohe Bay for experimental aquaculture in the 1970's, appear to be causing reductions in diversity and coral death.

In this study, extensive surveys were conducted in Waikiki for *G. salicornia* and in Kane'ohe Bay for *K. alvarezii* to examine potential patterns between invasion success and species diversity. An extensive historical dataset from Waikiki prior to the introduction of *G. salicornia* (late 1960's -mid 1970's) was used to assess changes in community structure and diversity since the arrival of the invader. The abundance of both invasive species is negatively correlated with species diversity, and significant differences were found in both species number and evenness when the invaders were present. Permanent photoquadrats were used to determine monthly changes in percent cover of the invaders and to determine rates of coral overgrowth and death. Both invaders can rapidly grow over and monopolize benthic substrates including live coral. In particular *K. alvarezii* is able to overgrow and displace reef-building corals at a rate of 10% increase per month. These results demonstrate significant negative impacts caused by invasive marine algae on coral reefs and suggest that the invasive species should be added to the list of factors leading to reef degradation worldwide.

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## BIOGEOGRAPHIC VARIATION IN CLAW SIZE AND PERFORMANCE IN AN INTRODUCED CRAB PREDATOR: EVIDENCE OF AN EMERGING ARMS RACE?

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### Oral Presentation

4:00 PM, Wednesday

Biological invasions provide outstanding opportunities to study nascent arms races as introduced predators and native prey come in contact. Greater understanding of the processes involved in an arms race, in turn, will permit better predictions of an invasion's outcome(s). To date, most research in marine systems has focused on community (or species) responses to an invader. Because performance often correlates with form, key unanswered questions are: to what extent can the invader respond morphologically and functionally to its new environment and are the responses inducible (i.e., occurring within vs. across generations)? As a first step, we have looked for evidence of latitudinal differences in claw size and performance in the introduced green crab (*Carcinus maenas*) on both Atlantic and Pacific coasts of the United States. On the Atlantic coast, morphometric analyses indicate that populations of green crabs in Massachusetts have larger major (crusher) claws than populations in northern Maine. In laboratory performance tests, Massachusetts's crabs were also able to crush larger snail prey than their northern counterparts. These patterns correlate positively with geographic differences in shell thickness of at least one species of rocky intertidal snail prey and suggest a developing arms race in the Gulf of Maine. Latitudinal differences in claw size were also detected in the more recent Pacific coast green crab invasion, but only for the minor (cutter) claw. The different spatial patterns in claw size may relate to differences in the duration of each invasion, substratum (and thus prey) type, or temperature regimes between the two coasts.

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## IDENTIFYING POTENTIAL INVADERS AMONG IMPORTED MARINE SPECIES

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### Poster Presentation

Monday

As a major center of commerce and research, New England imports large quantities and a high diversity of live marine species through different pathways. Many of these organisms have the potential to establish if they are released in New England waters. To minimize the risk of unwanted introductions, information is needed about: (1) which species are being imported, (2) the likelihood of their establishing in the region's waters, and (3) their potential for causing harmful ecological, economic, or health effects. To date, we have identified a number of imported species from questionnaires administered to New England organizations (e.g., seafood companies, bait shops, pet aquarium dealers, researchers) and from regulatory agency databases and websites. As a first cut, we have classified those species likely to survive in the annual range of temperatures found in New England estuarine and coastal waters. For each species meeting this criterion, we are creating a database using library and website resources that includes information on: geographic origin, general habitat requirements, life history characteristics and dispersal strategy, trophic interactions and diet, associated parasites and diseases, and history of invasions and impacts in other regions. A major problem in assembling a comprehensive database is inadequate and uneven reporting of species by almost all pathways surveyed. For example, species names were provided by 64% of researchers in our questionnaires, but by none of the seafood respondents. Databases maintained by regulatory agencies also vary in taxonomic specificity for most imports. Clearly, greater taxonomic resolution is needed if we are to begin to develop predictive models of invasion risk for New England or for other regions.

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## AN INTRODUCTION TO INVASIVE ALIEN ALGAE IN HAWAII: ECOLOGICAL AND ECONOMIC IMPACTS

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### Poster Presentation

Tuesday

Several species of red algae, including *Kappaphycus* spp., *Hypnea musciformis*, and *Gracilaria salicornia* were introduced to Hawaii's reefs in the early 1970s to study their feasibility for aquaculture. When experimental trials were completed, the plantings were abandoned. Thirty years later, all three of these species are proving to have significant negative impacts on reef ecosystems. *Kappaphycus* spp. was introduced to Kaneohe Bay on Oahu in 1974. Initial studies based on reproductive character determined that it would not be able to spread from the site of introduction. Today, *Kappaphycus* spp. is found throughout Kaneohe Bay and commonly overgrows and smothers corals. It reproduces readily by fragmentation and spore production. *Hypnea musciformis* was introduced to Oahu in 1974 as well. Since that time, it has spread to all of the major Hawaiian Islands, except Hawaii. It forms blooms that generate new biomass of up to 9000kg/wk, much of which subsequently washes up on West Maui beaches. The large piles of decomposing biomass draw complaints from residents and drive tourists away. A recent study has confirmed significant economic impact of this nuisance species (up to \$30 million/yr) in the form of lower property values and lost tourist revenue. *Gracilaria salicornia* was introduced to Waikiki and Kaneohe Bay, Oahu in 1971. Despite a long lag phase, it is now the dominant alga on the reefs fronting Waikiki Beach, with large (100m<sup>2</sup>) patches reaching up to 100% cover. After large south swells, this alga also washes up on beaches in huge quantities and prevents utilization of these areas. Given the documented economic impact to Maui, the spread of *Gracilaria salicornia* and other alien algae poses a serious threat to the economic health of Waikiki businesses. In summary, alien and invasive algae in Hawaii pose imminent ecological and economic threats to the State of Hawaii.

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## GENETIC INVESTIGATIONS OF SOURCE AREAS, SPREAD PATTERNS, AND CHANGES OVER THE TIME COURSE OF EXOTIC INVASIONS

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### Oral Presentation

2:15 PM, Monday

DNA data and risk analysis offer important diagnostic and monitoring tools for evaluating the success, spread patterns, and population interactions of exotic species invasions. Risk assessment may allow us to predict the number of introductions and founding individuals that characterize successful nonindigenous species invasions, as well as likely founding source pathways. Exotic invaders have become more common in the Great Lakes, presumably due to high shipping traffic, faster vessels, and a history of ecological disturbance. The round goby and a close relative of the quagga mussel are saline tolerant and are likely to spread to marine and estuarine habitats. The present study compares the levels and distributions of genetic variability in North American and putative Eurasian source populations for invasions of dreissenid mussels, ruffe fish, and gobies in the Great Lakes and explores its applications to risk assessment. Objectives are to: (1) evaluate the possible number and Eurasian source locations for introductions using DNA data, (2) analyze levels and patterns of genetic variation within and among native and introduced population sites, (3) test for founder effects and possible mixing from several founding sources, and (4) examine population changes over the time courses of the invasions. Results show that populations of dreissenid mussels and round gobies have surprisingly high levels of genetic variability, suggesting large numbers of founding individuals and consistent with multiple colonizations – both of which may be predictive of establishment risk. Slower spread of the ruffe and tubenose goby populations may be related to lower overall genetic variability and the likelihood of single founding events/sources. In conclusion, high genetic variability, large numbers of founders, and multiple founding sources likely significantly contribute to the risk of an exotic species introduction's success and persistence.

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## **THE ATLANTIC SALMON WATCH PROGRAM, A STUDY OF THE FIRST TEN YEARS 1991 - 2001**

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### **Oral Presentation**

3:00 PM, Tuesday

The Atlantic Salmon Watch Program (ASWP) was initiated in 1991 as a joint research program between Fisheries and Oceans Canada and the British Columbia Ministry of Agriculture, Fisheries and Food to study the occurrence of Atlantic salmon (*Salmo salar*) in British Columbia (BC). What was initially a passive data gathering program has evolved into a multifaceted study of the exotic introduction of Atlantic salmon in the North Pacific. From 1991 to 2001, a total of 413,027 Atlantic salmon have been reported escaped from marine aquaculture facilities in BC. The continued loss of this exotic species has become a focal point of the polarized debate over salmon aquaculture in BC. The ASWP now encompasses a wide ranging mandate of public relations, training programs, stream surveys, eradication programs, applied biological research as well as the original mandate of simple data collection. The first documented recovery of an Atlantic salmon in the North Pacific occurred in 1987, since that time, 18,431 Atlantic Salmon have been caught in the marine and coastal waters of BC. An additional 1051 adult Atlantic salmon have been observed or caught in the rivers, lakes and streams of BC. The first documented recovery of juvenile Atlantic salmon in BC occurred in 1996, three hundred and fifty-nine juveniles have been observed since that initial discovery. The ASWP conducted over 130 directed stream surveys to enumerate and eradicate Atlantic salmon in 2001.

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## **PATTERNS OF ANTIBIOTIC RESISTANCE IN CHOLERA BACTERIA ISOLATED FROM SHIPS' BALLAST WATER**

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### **Poster Presentation**

Monday

Ships' ballast water is a notorious vector in the inter- and intraregional dispersal of nonindigenous organisms. These invasive species often possess latent attributes that, when expressed outside the constraints of their native habitat, can have devastating effects on the invaded ecosystem. In the case of bacteria, the presence of numerous genetic variants and their associated phenotypic expressions may change our frame of reference from "invasive species" to 'invasive genotypes'. The possibility of horizontal gene transfer amplifies the risk associated with the transport of bacteria in ballast tanks and their subsequent release into receiving ports. In *Vibrio cholerae*, the etiologic agent of human cholera, antibiotic resistance is a trait with ramifications for human health concerns. Antibiotic susceptibility analyses revealed some form of antibiotic resistance in 76% of isolates collected in ballast water and residual sediments from the Great Lakes and Chesapeake Bay. Given these data, we envision three scenarios: 1) antibiotic resistance is being imported into Chesapeake Bay via ballast-water operations; 2) antibiotic resistance has been imported or was already present and the Bay is a net exporter; 3) horizontal gene transfer of antibiotic resistance occurs within ballast tanks, thus facilitating the expression of other undesirable phenotypes in previously susceptible organisms.

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## POPULATION DYNAMICS AND THERMAL TOLERANCES OF THE INVASIVE KELP, *UNDARIA PINNATIFIDA*, IN CALIFORNIA

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### Poster Presentation

Monday

During the past few years, *Undaria pinnatifida* has been found at several locations along the California coast. In its native range, this kelp is found in Japan and southeast Asia and is cultured extensively for human consumption. However, this kelp has spread worldwide during the past decades, through both accidental and purposeful introductions. However, the effect of this species upon native marine communities varies greatly across locations. Thus, the potential impacts of *U. pinnatifida* on nearshore communities in California cannot be predicted from previous studies. Here, we tracked the timing and magnitude of *U. pinnatifida* recruitment, growth, and subsequent reproductive onset in the Santa Barbara, California harbor from July 2001 to June 2002. We found two temporally distinct pulses of recruitment, and the growth and reproductive onset of these pulses differed greatly. The first pulse had few recruits (approx. 40 individuals), but many of these survived to adulthood. By contrast, the second pulse was much larger in size (approx. 300 individuals), but only one individual survived long enough to become an adult. There is a correlation between the timing of recruitment and the ocean temperature, and we conducted laboratory culturing experiments to determine the effects of water temperature on the growth of *U. pinnatifida*'s microscopic stages. We found differences in survival rates of microscopic stages grown at different temperatures, which can provide insight into the potential for growth and spread of *U. pinnatifida* along the west coast of North America.

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## INVASION DYNAMICS OF THE EUROPEAN GREEN CRAB, *CARCINUS MAENAS*, IN AUSTRALIA

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### Oral Presentation

12:15 PM, Tuesday

Direct measurements of the spread of planktonic larvae for any marine species are rare, due to practical limitations of tagging and tracking the larvae. We address this issue obliquely, by examining rates and patterns of range expansion by a widely introduced species, *Carcinus maenas*. *C. maenas* has a long planktonic duration (upwards of 50 days) and off-shore development, which would be assumed to facilitate dispersal and result in rapid rates of spread once the species has established itself. However, our data indicate that in Australia, and at most other invaded locations, rates of range expansion in the species are often very slow, on the same order of magnitude as the ability of tagged individuals to walk along the coast. This relative stasis is punctuated by rare episodes of long-distance and large scale spread, some of which appear to be related to unusual oceanographic conditions and some of which are likely to be human-assisted. The ability of *C. maenas* to maintain high levels of local recruitment, even in the presence of long planktonic durations and apparently obligate off-shore development, is likely to be a major factor in its success as an invasive species, and also implies strongly structured spatial metapopulations that will have impacts for potential management strategies.

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## INTRODUCED MARINE SPECIES AND THEIR MISSING PARASITES

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### Oral Presentation

4:45 PM, Wednesday

Escape from the effects of natural enemies is a frequent explanation given for the success of introduced species. Most notably, exotic species may be subject to fewer parasites and pathogens in their introduced range compared to their native range. To test whether introduced marine species escape their parasites, we examined parasite species richness and prevalence in introduced species from a broad range of marine taxa (molluscs, crustaceans, fishes), selected by a stratified random procedure. Compared to the number of parasite species found in native populations, only half as many parasitized exotic populations. Furthermore, introduced populations were less heavily parasitized (% infected) than were native populations. Reduced parasitization of introduced marine species has multiple causes. These include reduced probability of introduction of parasites with exotic species (or early extinction following host establishment), absence of other required hosts in the new location and the host-specific limitations of native parasites adapting to novel hosts. These results are consistent with a more extensive study including freshwater and terrestrial taxa. They support the hypothesis that introduced species become pests because, at least in part, they lack natural enemies. Hence, use of natural enemies in control strategies may reduce adverse impacts of exotics on native species.

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## CHANGES IN CARBON AND NITROGEN CYCLING IN PACIFIC ESTUARIES FOLLOWING *SPARTINA ALTERNIFLORA* INVASION

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### Poster Presentation

Tuesday

We know little about how estuarine invaders alter the storage and cycling of C and N because ecosystem-level changes resulting from nonindigenous species invasions have rarely been investigated. The recent, rapid expansion of Atlantic smooth cordgrass, *Spartina alterniflora*, into Pacific estuaries has fostered a large-scale alteration in ecosystem processes as low-stature marshes and mudflats are invaded. Estuary-wide changes in carbon (C) and nitrogen (N) cycling occur with the shift from a system dominated by fast-growing microalgae and phytoplankton that turnover rapidly throughout the year, to a system dominated by a large, highly productive vascular plant that builds considerable aboveground biomass during the spring and summer but senesces entirely in the fall. Substantial roots and rhizomes persist year-round. We present here a preliminary investigation of spatial and temporal changes in C and N dynamics in San Francisco Bay, CA and Willapa Bay, WA that have resulted from the *S. alterniflora* invasion. During invasion, the build up of biomass is so rapid and substantial that the phenology of aboveground plant growth and subsequent shuttle of large stores of C and N below ground represents a considerable shift in allocation patterns relative to a microalgal-dominated mudflat. We also examined changes in C & N storage following eradication attempts in Willapa Bay. Aboveground material is immediately removed, but belowground roots, rhizomes and organic detritus persist for many years. This vestigial detritus has important implications for ecosystem recovery and may be linked to infaunal and algal production. This study will provide one of the first studies of the ecosystem changes caused by *Spartina alterniflora* invasion.

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**ASSESSMENT OF LIVE INVERTEBRATES AND RESTING STAGES  
FROM NOBOB VESSELS ENTERING THE GREAT LAKES:  
POTENTIAL VECTORS FOR NEW INVASIONS**

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**Oral Presentation**

5:15 PM, Monday

Ballast water has been an important vector for the introduction of nonindigenous species into the Laurentian Great Lakes, and the majority of vessels that enter this system are laden with cargo and declare no ballast on board (NOBOB) status. Ballast exchange regulations, implemented in 1993, do not apply to NOBOB vessels despite the fact that unpumpable residual salt-, brackish-, or fresh-water, and associated organisms may be contained within these ballast tanks. This residual water may then eventually be released into the Great Lakes after ballast loading and unloading events are conducted within the system. This potential invasion vector is previously unexplored.

We sampled residual water from 48 tanks on 24 ships inbound to the Great Lakes and recorded two rotifer and 29 microcrustacean species, predominantly cyclopoid and harpacticoid copepods. Furthermore, we examined the potential invasion risk owing to the presence of viable invertebrate resting eggs contained within residual sediments from the ballast tanks. Sediments were collected from 33 tanks on 20 vessels. The density and viability of resting eggs varied widely, from 0.3 to 91.3 eggs/g sediment, and 0 to 92%, respectively. Viability of resting eggs was explored under various day length and salinity conditions. Thirty fresh and brackish water species have been identified to date, at least four of which are not currently established in the Great Lakes.

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## THE PREVALENCE OF NONINDIGENOUS SPECIES IN SOUTHERN CALIFORNIA EMBAYMENTS AND THEIR EFFECTS ON BENTHIC MACROINVERTEBRATE COMMUNITIES

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### Oral Presentation

1:45 PM, Wednesday

We assessed the prevalence of nonindigenous species in the benthic macrofauna of southern California embayments from 123 samples collected in 1998. Nonindigenous species were prevalent, occurring in all but two samples. They accounted for only 27 of 633 taxa (4.3%) but contributed 27.5% of the abundance.

Nonindigenous species were more prevalent in southern California embayments than other areas in a 1999 study that excluded San Francisco Bay. Nonindigenous species occurred at 100%, 33%, 71% and 68% of sampling sites in southern California, northern California, Oregon and Washington, respectively. On average, they contributed 22.7%, 2.6%, 14.1%, and 6.0% of abundance and 11.9%, 2.8%, 15.1% and 10.8% of the taxa in each sample.

In southern California embayments, there were no apparent differences in nonindigenous species abundance, proportional abundance or composition among ports servicing large ocean-going vessels, small boat marinas, or areas where boats were not moored.

Nonindigenous species abundance in southern California embayments was positively correlated with the abundance and richness of other species; there was no negative impact at this gross level. However, negative effects on specific native taxa cannot be ruled out without further study.

Three of the five most abundant species in southern California Bays, *Pseudopolydora paucibranchiata*, *Musculista senhousia*, and *Theora lubrica*, were nonindigenous. They accounted for 92% of nonindigenous species abundance. All three species were widespread. *M. senhousia* dominated southern embayments while *T. lubrica* dominated Los Angeles - Long Beach Harbor and Anaheim Bay. Large numbers of *P. paucibranchiata* occurred in every bay.

The positive correlations between nonindigenous species and other species were likely related to biogenic structures. The thick mats of byssal threads created by *M. senhousia* and the tubes built by *P. paucibranchiata* create niche space for many other species. *T. lubrica*, a small bivalve, has the least effect.

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## HABITAT USE OF JUVENILE CHINESE MITTEN CRABS IN THE SACRAMENTO-SAN JOAQUIN DELTA

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### Poster Presentation

Tuesday

The catadromous Chinese mitten crab (*Eriocheir sinensis*) was first collected in San Francisco Estuary, California, USA, in 1992. *E. sinensis* rapidly expanded in distribution and abundance. The current distribution is the entire San Francisco Estuary and low elevation tributaries. A portion of the population of juvenile *E. sinensis* rear in the Sacramento-San Joaquin Delta, which is the eastern portion of the San Francisco Estuary where several rivers join to form a large, tidal, freshwater wetland. To determine the habitats potentially impacted by *E. sinensis*, we investigated the spatial and temporal distribution of juvenile crabs among subtidal habitats of the delta. Presented are the results of three studies that occurred in the delta during 1998-2001. One study was a focused investigation of *E. sinensis* habitat use. The other two studies were fish investigations and *E. sinensis* was collected as bycatch. By comparing the results of these studies, several trends became apparent. Juveniles were most abundant during summer and fall months corresponding with physiochemical attributes temporally characterized by warm water temperatures ( $>20^{\circ}\text{C}$ ) and low freshwater outflow ( $\sim 19000\text{m}^3/\text{s}$ ). Spatially, juveniles were most abundant in shallow areas (0-2.5m) with submerged aquatic macrophytes and mud substrates. Abundance was higher in the western delta compared to the central delta. We conclude that shallow areas with macrophytes provide favorable rearing habitat for juvenile crabs as it supports biotic (i.e., prey abundance) and abiotic (i.e., cover from predators) conditions compatible with mitten crab rearing strategies. The proximity of the western delta to the brackish water zone (area of megalopa settlement) may be a factor in the geographic distribution of juvenile crabs. Therefore, within the delta, *E. sinensis* may have the greatest impact on shallow freshwater habitats with aquatic macrophytes located near the brackish water zone.

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## A COMPARATIVE ANALYSIS, BASED ON MOLECULAR ECOLOGY AND POPULATION GENETICS, OF THE INVASION BY THREE GASTROPODS IN AREAS OF OYSTERS CULTIVATION

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### Oral Presentation

2:00 PM, Monday

Expansion and contraction of the area colonized by a species is a natural process over evolutionary time scales. However, sudden range expansions have been observed at an increasing rate since the end of the 19th century. Numerous conceptual frameworks and methodological outlines have been developed (1) to investigate the history of the invasion processes and subsequent dispersal, (2) to determine the effects of the new species and (3) to make predictions for the control of the invasion process. By modifying the genetic characteristics and architecture in invasive populations, evolutionary forces such as selection or genetic drift play a major role in determining the spread and the long-term establishment of alien species. Interestingly, even though genetic and evolutionary processes are key features of marine bioinvasions, population genetics methods have not yet been fully exploited.

We carried out researches on three gastropods in the framework of French National Program for the Study of Biological Invasion. We here present a short review of these studies based on population genetics and molecular ecology approaches. The three species, *Crepidula fornicata*, *Ocenebrillus inornatus* and *Cyclope neritea*, are native of the East coast of USA, Asia and the Mediterranean Sea, respectively, and were accidentally introduced in France in the 1940s, 1990s and 1970s respectively. We analyzed the genetic patterns of these species in order to trace the historical processes (number and locations of the source populations). One of our goals was to analyze the roles played by the mode of transportation and the life-history traits in the success of these species. Interestingly, common genetic properties and patterns were revealed suggesting that the success of these species is largely due to recurrent introduction events involving a large number of founders regardless of the specific biological characteristics.

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## HABITAT BIAS IN MARINE INVASIONS OF CENTRAL CALIFORNIA

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### Oral Presentation

8:30 AM, Wednesday

We carried out a two-part investigation that revealed habitat bias in marine invasions. First, we compared invasibility of hard vs. soft substrate habitats in Elkhorn Slough, an estuary in central California, by comparing abundance and richness of native vs. non-native species in quantitative samples from each habitat type. Our results reveal that the hard substrates are much more heavily invaded than the soft substrates; the infaunal mudflat community is dominated by native species, while the fouling community on rocks and shells is dominated by non-native species. Nearly all the hard substrates in Elkhorn Slough, as in most estuaries along the Pacific coast of North America, are artificial (jetties, rip-rap, docks, etc.). The absence of an extensive native fouling community adapted to hard substrates may facilitate invasions of this habitat type. Moreover, two major vectors responsible for marine introductions, oyster culturing and ship-hull fouling, are much more likely to transport fouling species than mudflat infauna.

The second component of our investigation consisted of a comparison of estuarine and open coast invasion rates. We examined native vs. non-native species richness in Elkhorn Slough and adjacent rocky intertidal habitats along the central California coast from Carmel to Pigeon Point. The absolute number of non-native species in the estuary was about an order of magnitude higher than along the open coast. Moreover, non-natives accounted for over 10% of the richness of the estuarine fauna, while they comprised less than 1% of the richness of the open coast fauna. The strikingly higher invasion rate of estuaries vs. open coasts may be the result of multiple factors, including greater human alteration of estuaries, less rich native estuarine communities to provide biotic resistance, and greater influence of transport vectors bringing invasive propagules to estuaries.

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## THE LIVE MARINE SPECIES TRADE AND POTENTIAL RISKS FOR EXOTIC SPECIES INTRODUCTIONS

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### Oral Presentation

1:45 PM, Tuesday

Introductions of nonindigenous species can adversely affect marine ecological communities. To prevent unwanted introductions, it is critical to identify current invasion pathways and to understand their dynamics. While ballast water transport is a primary mechanism, it is not the only one, and its relative importance may vary from region to region. Our study was designed to (1) identify non-shipping pathways for marine invasive species into and out of New England coastal states, (2) rank these as to relative risk of unintentional release, and (3) work with stakeholders to mitigate risks. We assessed potential risks associated with the following pathways: seafood companies, aquaculture facilities, bait shops, pet stores, marine research laboratories, public aquariums, and wetland restoration projects. We compiled a database of organizations for each pathway and administered a general survey to subsets of these organizations to gather comparative data on: points of origin or destination of nonindigenous, identity of the species, frequency and volume of trade, mode of transport, likelihood of inclusion of non-target organisms in trading activities, organization's awareness of problems related to nonindigenous, existing safeguards to prevent accidental release, and economic value of nonindigenous transfers to the overall operation. Study results demonstrated that each of the seven pathways were moving live marine species into New England and they varied in the types of risky features that may lead to an exotic species introduction. In order to enact effective control measures for marine bioinvasions in New England, a pathway-specific approach to risk management is needed. Findings from this study are being used to guide invasive species prevention strategies and management actions for non-shipping pathways in the northeastern United States.

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## CHLORINE TREATMENT OF *CAULERPA TAXIFOLIA*

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### **Oral Presentation**

8:45 AM, Monday

The eradication program for *Caulerpa taxifolia* in southern California is based on exposing the seaweed to chlorine bleach. I performed a series of laboratory experiments to test the response of fragments of *C. taxifolia* to 4 concentrations of chlorine over durations of 30 -120 minutes, under both warm temperatures favorable to growth and ambient seawater temperatures on the northern Californian coast. At 125 ppm Chlorine, all fragments were killed within 30 minutes. Fragments survived and even regenerated at lower concentrations at 23°C. Cold shock resulted in apparently dead fragments in both controls and bleach treatments; however, chloroplasts were translocated into tissue anchored in the sediments. At the end of 4 months, no aboveground growth was produced from such fragments in cold water. The results indicate that chlorine levels should be maintained >125 ppm in the field eradication program where the organic load is considerably greater. Furthermore, accidental release of fragments from quarantine facilities or warmer bay waters into the cold waters of the open coast in northern California is not likely to lead to establishment of a new population.

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## MESOHALINE BRACKISH-WATER FAUNA IN NORTH-WEST EUROPE: 100% NONINDIGENOUS?

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### Oral Presentation

11:00 AM, Tuesday

Brackish waters in northwestern Europe contain a limited number of macrofaunal brackish-water species. Under mesohaline conditions (5–18 psu) we find a common set of about 30–35 species in all NW-European estuaries. A few other species occur only in stagnant lagoons with less rapid salinity fluctuations.

Of these 30–35 species we have evidence that over 10 species (>30%) have been introduced through human assistance. At least another 5 species can be considered cryptogenic. This implies that about half of the macrofaunal species in NW-European may be nonindigenous.

In earlier papers I have proposed the hypothesis that the paucity of species in NW-European brackish waters has been caused by the last Ice Age. During each glacial-interglacial cycle brackish-water all species had to migrate South and back again along a series of strongly discontinuous habitat ‘islands’. It is hypothesized that many species were lost during these migrations, i.e. they became extinct. Some support is found in comparisons of interglacial molluscan faunas with the holocene one.

Hence, the question is raised how many former European brackish-water species have survived the Ice Age. I suggest that the answer should be “almost none” and that the present brackish-water fauna of NW Europe is made up of euryhaline coastal fauna, euryhaline freshwater fauna, and nonindigenous brackish-water species.

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## MULTIPLE POSITIVE INTERACTIONS AMONG MUDFLAT INVADERS

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### Oral Presentation

11:30 AM, Monday

Introduced species can affect both native species and other invaders. Between invading species, positive interactions will tend to facilitate invasions, negative interactions will tend to inhibit them, and the effect of mixed interactions will depend on the order in which species invade. Facilitation between invaders has been proposed as a mechanism to explain the pattern of increasing invasion rates and impacts.

Here, we report positive impacts of an invasive Asian mud snail, *Batillaria attramentaria* (Brugière 1792), on members of an intertidal community in Padilla Bay, Washington, USA. Survey and literature data show that *Batillaria* shells are used as substratum by the Asian anemone, *Diadumene lineata*, and the slipper shell *Crepidula* sp.; empty shells are inhabited by native hermit crabs, *Pagurus* spp.; and the invader serves as a host for the introduced Asian parasitic trematode, *Cercaria batillariae*. Experimental results show that the density of the introduced Asian mud snail, *Nassarius fraterculus*, and percent cover of the introduced Asian eelgrass, *Zostera japonica*, are significantly reduced in *Batillaria* exclusions. Thus, the presence of *Batillaria* is associated with increased densities of both introduced and native species. Although *Batillaria* is a surface diatom grazer, we documented no effects of its removal on sediment chlorophyll levels or on infaunal densities, a result which may reflect low power in the sampling design.

Since history does not record the exact arrival dates of these invaders, the role of their positive interactions in contributing to an accelerating invasion rate is unknown. On the other hand, since *Batillaria* appears to encourage greater population densities of other introduced species, it presumably allows their total effects to be greater than they would be otherwise. Although we cannot evaluate whether the *Batillaria* invasion contributed to increased invasion rates, we hypothesize that it currently contributes to increased total invasion impacts.

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## STATUS OF THE *CAULERPA TAXIFOLIA* ERADICATION EFFORT IN SOUTHERN CALIFORNIA

Woodfield, R. A., Merkel & Associates, Inc., San Diego, CA, USA, rachelannw@aol.com

### Poster Presentation

Monday

In June 2000, the invasive alga, *Caulerpa taxifolia*, was discovered in Agua Hedionda Lagoon in Carlsbad, California. A second infestation was then confirmed in Huntington Harbour in Huntington Beach, California. Genetic analysis has confirmed that the *Caulerpa* is the highly invasive aquarium strain that has reportedly caused economic and ecological damage to the six other countries where it has been introduced. Upon its discovery in California in 2000, an eradication effort was immediately undertaken by the Southern California *Caulerpa* Action Team's contractor to contain and kill the seaweed at both sites. The first year's work involved aggressive treatment by covering the alga in-situ with heavy PVC tarps and applying chlorine to the area under the sealed tarps. The second year's efforts involved continual surveillance for and treatment of residual patches of *Caulerpa* not previously detected. In Carlsbad, the original area of the infestation was 1076m<sup>2</sup> in June 2000. Two years later, 0.4m<sup>2</sup> was found. Since that time, two more surveys of the infestation area have been conducted with no *Caulerpa* found. Similar results have been found in Huntington Harbour, with none found during the most recent survey. Although the results are promising, field observations demonstrate that any lapse in detection of even a small occurrence can result in rapid growth and spread. Quarterly surveys will continue in order to find patches any remaining patches. The hope is that all *Caulerpa* will be found and treated at these sites within five years, with a minimum of two years of follow-up survey.

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## SPREAD RATES AND EFFECTIVENESS OF MANAGEMENT STRATEGIES FOR *CAREX KOBOMUGI* (ASIATIC SAND SEDGE) IN TWO NEW JERSEY COASTAL PARKS

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### Oral Presentation

4:15 PM, Monday

Asiatic sand sedge, *Carex kobomugi*, was accidentally introduced to North America approximately a century ago and then deliberately introduced into dune systems for decades for its dense foliage and disease- and trampling-resistant properties. This, combined with natural propagation, resulted in the species' expansion into numerous habitats from North Carolina to Massachusetts. To assess current spread rates and impacts on dune ecology, stands of *C. kobomugi* in two New Jersey parks, Island Beach State Park (IBSP) and Sandy Hook Unit (SHU) of Gateway National Recreational Area, were mapped in 2002. Relative to a 1985 survey in IBSP there was an increase of approximately 300% in number of beds, 400% in bed size and 55% in *Carex* stem density. Stem densities of native species, as well as overall species diversity, were generally lower inside *C. kobomugi* stands than out. A pilot eradication project at SHU in the late 1990s, using a backhoe and sifter, failed to effectively remove a small *C. kobomugi* stand, probably because this species' roots routinely reach >1.2m deep. Restrictions on chemical use in Federal Parks have halted further treatments at SHU pending future management recommendations. By contrast, at IBSP an eradication program based on tightly controlled application of Roundup® onto individual *C. kobomugi* plants was initiated in 1999. In 2002 we assessed treated beds. A single Roundup® application reduced *C. kobomugi* abundance approximately 70%, but left living *Carex* in 95% of the 1m<sup>2</sup> quadrats surveyed. Repeated herbicide applications reduced *C. kobomugi* abundance by about 90% and viable individuals to 55% of quadrats. Native plant abundance and species diversity in treated versus untreated beds was similar, suggesting low-impact pesticide application effectively spared remaining native plants. However effective eradication of *C. kobomugi* would probably require more aggressive, broadband herbicide application, precluding beneficial effects (both ecological and increased dune stability due to spared plants) of localized treatment.

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## BIOTIC AND ABIOTIC FACTORS IN THE INVASION SUCCESS OF A CARIBBEAN BARNACLE IN HAWAII

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### Oral Presentation

10:45 AM, Tuesday

One of the goals of invasion biology is to understand the conditions that make invasions succeed or fail. While biotic interactions might limit invaders, abiotic processes are also likely to be important. To gain insight into this matter, we studied a number of factors that seemed likely to impact the course of an invasion in Hawaii.

The Atlantic barnacle (*Chthamalus proteus*) is one of the most abundant recent invaders in the Hawaiian intertidal. Its distribution in Hawaii is generally limited to protected bays and harbors. Smaller populations are found in areas with moderate wave intensity, where the invader co-exists with a number of native species, including the barnacle (*Nesochthamalus intertextus*). To determine whether biotic interactions might be limiting the barnacle's distribution, laboratory and field experiments were used to examine competition for space with *N. intertextus* and a native pulmonate limpet, *Siphonaria normalis*, and predation by a native whelk, *Morula granulata*. These interactions do not appear strong enough to limit the spread of *C. proteus*.

Surveys in Curacao and Panama indicate that *C. proteus* uses similar habitat types in its native range and in Hawaii. These data suggest that physical factors may limit the spread of the invader and provide some measure of protection for native communities on the open coast. On the other hand, habitat modifications that increase hard substrata and decrease wave action are likely to facilitate spread of the invader.

Biotic and abiotic factors may work together to determine the course of an invasion. Outcomes of a competition experiment were different between the first and second years, during which oceanographic conditions changed from La Nina to normal. Additional experiments suggest that variation in density of the invader – most likely the result of physical factors – can also change the outcome of competition between *C. proteus* and other barnacles.

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