GENETICAL AND ECOLOGICAL EFFECTS OF THE INTENTIONALLY INTRODUCED RED KING CRAB (PARALITHODES CAMTSCHATICA) AND THE ACCIDENTALLY INTRODUCED SNOW CRAB (CHIONOECETES OPILIO) IN THE BARENTS SEA AREA

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Key Words: Introduction of crab species, Barents sea, genetical and ecological effects

The Red king crab (Paralithodes camtschatica) was intentionally introduced from the Sea of Japan to the Barents Sea in the 1960ís. Since that time, this species has not only successfully survived, but the population is growing in number as well as increasing the distribution range. In 1996, the first discovery of the occurrence of Snow crab (Chionoecetes opilio) was made in the Barents Sea area by PINRO in Murmansk. One female and 4 males were caught, and all males were mature when comparing with biological information obtained from other snow crab populations in other distribution areas. This species has probably been introduced accidentally through ballast water.

Introductions of alien species are considered as one of the main threats for maintaining biodiversity, and any new introduction, intentionally or accidentally, should be carefully monitored. In light of this it is of uttermost importance to explore and elucidate the genetical and ecological effects of the "new" crab species into the new areas. Obviously there will be competition with other crab species in the area for food, shelter etc, but likely also with commercially exploitable species as capelin (Mallotus villosus), cod (Gadus morhua) and wolf fish (Anarchichus minor and A. lupus).

The genetic characterisation of introduced populations and comparisons with donor populations must be done. The level of genetic variability can be important for new adaptations and potential spread into new areas. At present, little information is available about potential ecological effects of the introduced crab species into the Barents Sea region. Long-time bottom-trawl records at IMR and PINRO can, however, be evaluated to look for any changes after the introduction of King crab in the Barents Sea. Further, fish eggs are found in stomach of the king crab, and the distribution range overlaps with important spawning grounds of capelin in Finmark. Thus, a more detailed investigation to assess predation on capelin eggs, and compare with previous information of the spawning area is needed to be conducted. Further, management and legislative approaches will be outlined.

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NONINDIGENOUS PATHOGENIC SHRIMP VIRUS INTRODUCTIONS INTO THE UNITED STATES: DEVELOPING A QUALITATIVE ECOLOGICAL RISK ASSESSMENT

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Key Words: nonindigenous pathogenic virus, ecological risk assessment, shrimp, stakeholders

Public concerns over the potential introduction and spread of nonindigenous pathogenic shrimp viruses to shrimp aquaculture and to the wild shrimp fishery in the U.S. are increasing. Although these viruses pose no threat to human health, outbreaks on U.S. shrimp farms, the appearance of diseased shrimp in U.S. commerce, and new information on the susceptibility of shrimp and other crustaceans to these viruses prompted the Federal Interagency Joint Subcommittee on Aquaculture (JSA; National Science and Technology Council) to initiate an ecological risk assessment. The risk assessment process considered both EPAís Guidelines for Ecological Risk Assessment and the Aquatic Nuisance Species Task Forceís Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process. The JSA presented a preliminary report (Shrimp Virus Report), structured according to the problem formulation phase of a risk assessment, to stakeholders in the shrimp industry, several state and Federal agencies, environmental organizations, and the public, at meetings held around the southeastern U.S. and the Gulf of Mexico. Subsequently, under the auspices of the JSA, the EPA sponsored a qualitative ecological risk assessment conducted by a group of scientific and technical experts at a public workshop. Here, we describe workshop conclusions regarding risks associated with shrimp viruses, and preliminary results of a risk management workshop. We also identify lessons learned during the stakeholder process, and the strengths and limitations of the overall approach for assessing the risks of biological stressors over a large geographic region.

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THE INTRODUCTION OF POLYCHAETES HYDROIDES ELEGANS (HASWELL), POLYDORA LIMICOLA ANNENKOVA, PSEUDOPOTAMILLA OCCELATA MOORE INTO THE NORTH-WESTERN PART OF THE SEA OF JAPAN

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The polychaeta fauna of the benthos and fouling of the north-western part of the Sea of Japan was studied during the period of 1971-1998. Three introduced species of polychaetes: Hydroides elegans (Haswell), Polydora limicola Annenkova, Pseudopotamilla occelata Moore were found. H. elegans was discovered only on the artificial surfaces in Zolotoy Rog Bay (port Vladivostok), where this species may occur because of "thermal pollution" due to the discharge of warm waters of the water cooling system of Thermal-Electric Power Station-2 (TEPS-2) in Vladivostok which has been in function since 1971. The abundant population H. elegans exists in the bay throughout the year and is capable of reproduction. The biomass of H. elegans may reach several kg/m2 in August - September. P. limicola was found at the same time in the fouling of hydrotechnical structures of Vladivostok, Nakhodka, Holmsk and Uglegorsk ports with a biomass of 1-3 kg/m2. Slow introduction P. limicola occurs by coastal sail ships at present.

The invasion of P. occelata into the Peter the Great Bay may be an example of introduction and subsequent naturalization, which produced considerable changes in the structure of benthic communities. The three species of polychaetes sessile organisms and their invasion occurred by ocean and coastars sea-going ships (unintentional transport vectors). H. elegans and P. occelata were most probably transported to the north-western part of the Sea of Japan from Japan, and P. limicola from the Kamchatka Peninsula.

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MICROSATELLITE DNA ANALYSIS OF NATIVE AND INVADING POPULATIONS OF EUROPEAN GREEN CRABS

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Key Words: Carcinus, population bottleneck, population genetics, microsatellite DNA

Analysis of molecular genetic variation in introduced and native populations can help to localize the geographic sources of biological invasions and can provide insight into gene and population dynamics associated with successful invasion events. The multiple worldwide invasions of the European green crabs of the genus Carcinus provide an excellent model system to evaluate the utility of a molecular genetic approach for the study of marine invasions. We developed five polymorphic microsatellite DNA markers for green crabs to complement concurrent analyses of mitochondrial DNA. Our nuclear DNA analysis was unable to confirm hypotheses that South Africa and Japan were multiply invaded by the sibling species C. maenas and C. aestuarii, as was suggested by mitochondrial DNA analysis. Similarities in allelic composition indicate that the west coast of North America was invaded by green crabs that originated from an introduced population on the eastern North American coast, while crabs in Tasmania appear to have originated from an introduced population in Australia. Significant population structure was not detected among samples of native crabs from the Atlantic coast of Europe, precluding geographic localization of the native sources for C. maenas invasions.

Invasions were accompanied by large reductions in average heterozygosity and the average number of segregating alleles per locus. Average heterozygosity for introduced populations was 7 to 31% less than for native populations. Invasions that were inferred to have proceeded in a stepping stone pattern showed serial reductions in genetic diversity with each step. The magnitude of heterozygosity losses for introduced populations is consistent with extremely small founding population sizes (2-20 individuals) and/or genetic bottlenecks that lasted for several generations. Current work is focussed on the use of explicit population genetic models and Monte Carlo simulation techniques to more precisely estimate founding population sizes and post-invasion population dynamics.

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REESTABLISHMENT OF A NATIVE OYSTER: NATURAL EVENT OR HUMAN IMPACT?

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Key Words: estuaries, oysters, disturbance, indigenous species

The Olympia oyster, Ostrea conchaphila (=lurida) is native to the Pacific coast of North America. Although it survives in full seawater, significant populations occur only in estuaries with stable euryhaline zones (22-28 ppt). South of Washington State, such estuaries are sparse and often highly isolated. These habitats formed from drowned valleys during post-glacial sea level rise, and some have subsequently been altered by natural sediment deposition which eliminated the euryhaline zone and O. conchaphila populations. One such habitat appears to have been Coos Bay, Oregon, in which O. conchaphila thrived in the late Holocene, but went extinct prior to European settlement. A major deliberate inoculation of O. conchaphila from another estuary in 1917 failed to reestablish this species in Coos Bay. In 1987, however, following many years of minor accidental inoculations via shellfish transfers (of nonindigenous, cultured Pacific oysters, Crassostrea gigas) from other estuaries, O. conchaphila reestablished in Coos Bay, and has maintained a large population since then.

The adult distribution of O. conchaphila in Coos Bay is clearly correlated with salinity distribution patterns of a stratified estuary. Based on bathymetry and early salinity data, salinity distribution in Coos Bay has changed markedly since 1917, due to channel dredging. The main channel depth has more than doubled, permitting high salinity to intrude and again producing a stable euryhaline habitat suitable to O. conchaphila, similar to the situation prior to natural sediment deposition. Natural events created and then destroyed a habitat for a native species. Human activities of a "destructive" nature (dredging) have apparently restored this habitat for O. conchaphila. Furthermore, the mostly likely vector for reestablishment of this native species is shellfish transfer, more often associated with accidental introduction of harmful nonindigenous species.

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THE ARRIVAL OF THE EUROPEAN GREEN CRAB, CARCINUS MAENAS, IN OREGON ESTUARIES

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Key Words: European Green Crab, Carcinus maenas, Oregon, invasion

Since its first discovery in Coos Bay, OR in 1997, Carcinus maenas, is now found in at least five Oregon estuaries: Coos, Alsea, Yaquina, Netarts and Tillamook. Exuvia were found in three more: the Coquille, Siletz and Salmon estuaries. All the Carcinus maenas found in Coos Bay in 1997 were large crabs, ranging in size from 54-86 mm CW (carapace width). We estimate that they represent the 1995/1996 year class. Similar sized crabs were found in Tillamook and Netarts Bays this year. During the summer of 1998, a new year class appeared in Oregon estuaries as well as in Humboldt Bay, CA to the south and Willapa Bay and Grays Harbor, WA to the north. These crabs averaged 14 mm CW in June, 27 mm in July and 48 mm in August. This coast-wide colonization event is correlated with unusually strong northward moving coastal currents off the Oregon coast from September 1997 to spring of 1998. Transport of larvae from well established populations to the south, rather than oyster transport, appears to be the dominant mechanism for the appearance of this new year class.

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SHELLFISH CULTURE AS A VECTOR FOR BIOLOGICAL INVASIONS

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Key Words: polychaetes; shellfish culture; oysters

The introduction of seed stocks of nonindigenous commerical shellfish has acted as a vector for the introduction of exotic marine invertebrates into U.S. coastal waters. The most important consumable oysters in U.S. restaurants are not indigenous. On the Pacific coast, the Japanese Oyster, Crassostrea gigas has been cultivated for more than 50 years. Formerly, seed stocks were imported from Japan and set out on tidal flats to grow and mature. On the Atlantic coast, the European Oyster, Ostrea edulis was imported in a similar manner. Although modern culture methods include rearing of larvae in local laboratories rather than importation of juveniles, there is considerable evidence that many species of polychaetes were probably imported with the oyster seed stocks. The distribution of polychaetes by this vector may account for the wide distribution of some species. Two types of polychaetes are capable of transportation with seed stocks: (1) shell borers that form tunnels or channels in the shell itself; and (2) soft-sediment worms that are transported in mud on and between the shells. Shell borers that appear to have been transported in this manner include: Polydora websteri and P. brevipalpa. Sediment dwellers include: Polydora cornuta, Pseudopolydora kempi, P. paucibranchiata, Phyllodoce mucosa, Harmothoe imbricata, and Nereis succinea. An additional mode of transportation is with the direct importation of marketable products from a source country to a host country where the shellfish is sold in local markets. For example, in the early 1980's large specimens of a nonindigenous shell boring spionid, Boccardia acus, were found in a New Zealand mussel that was for sale at a fish market in Honolulu. This review suggests mechanisms of establishment for several nonindigenous species of marine polychaetes and recommends strong quality control measures intended to protect local shellfish from damage caused by exotic shell borers.

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PREY PREFERENCES OF THE RECENTLY-INTRODUCED WESTERN PACIFIC SHORE CRAB, HEMIGRAPSUS SANGUINEUS, FEEDING ON MOLLUSCS AND MACROALGAE IN SOUTHEASTERN MASSACHUSETTS

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Key Words: Hemigrapsus sanguineus, crab, molluscs, macroalgae, prey preference, predation

The prey preferences of the recently-introduced Western Pacific shore crab, Hemigrapsus sanguineus, were investigated to gain insight into the crab's potential to alter New England rocky intertidal ecosystems through predation. Laboratory experiments were conducted to determine prey preferences of the crab feeding on molluscs and macroalgae of the area. H. sanguineus were collected from the rocky intertidal zone of two southeastern Massachusetts sites from June to October 1998. Prey selection was examined in relation to mollusc prey of different size and species. Crabs of three size classes (12-18mm, 19-25mm, 26-31mm) were offered three mollusc species: the bivalves, Mytilus edulis and Mercenaria mercenaria, and the gastropod, Littorina littorea. Equal ratios of prey from three size classes were offered concurrently to indicate size preference. In another set of experiments, equal ratios of each species of the preferred size were offered simultaneously to determine species preference. When presented with a range of prey sizes, crabs selected small sizes, male crabs opening larger sizes than females. Crabs offered macroalgae in both multiple-choice and no-choice experiments readily consumed green algae in the laboratory. Enteromorpha spp., Ulva lactuca, Codium fragile, Chondrus crispus, Polysiphonia spp., Fucus spp., and Ascophyllum nodossum were presented to individual crabs separately to determine consumption rates and together to ascertain species preference. Additional feeding trials will examine the crab's preference for animal or plant material by presenting individual crabs with both mollusc and macroalgae species found to be preferred by previous experiments.

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GEOGRAPHIC DIFFERENTIATION OF AN INTRODUCED CRAB SPECIES (HEMIGRAPSUS SANGUINEUS) ON THE ATLANTIC COAST OF NORTH AMERICA

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Key Words: Hemigrapsus sanguineus, population genetics, RFLP, biological invasions, crabs

The shore crab, Hemigrapsus sanguineus, native to the western Pacific Ocean, was first discovered in the eastern United States in September, 1988 in Cape May County, New Jersey. Since then, H. sanguineus has been found in coastal areas from southeast Massachusetts to North Carolina. H. sanguineus was likely introduced via ballast water from ships traveling from the western Pacific. Introduced species often have detrimental ecological effects on their new environments. Understanding the mechanisms of species introduction and their subsequent spread is very important. Restriction enzyme digest patterns of mitochondrial DNA obtained from individuals collected in Massachusetts, New Jersey, North Carolina, and one location in Japan are being compared. The hypothesis of multiple introductions predicts that the patterns obtained from crabs from at least two locations will be distinctly different. The degree of difference will be used to infer the degree of allelic variation within and between the populations. The presence of near-identical patterns from individuals along the East coast will support the hypothesis that either a single introduction of H. sanguineus, or multiple introductions from the same source, has occurred. Primers specific for the mitochondrial cytochrome c oxidase subunit I (COI) gene successfully amplified a 700 bp region of DNA from individuals from Massachusetts. Seven of twelve assayed restriction digests of this PCR product showed multiple bands and can be used for genetic comparison. Currently the study is being extended and DNA from 30-50 individuals from each sampling location will be amplified with COI primers, and will subsequently be restriction digested with the same 12 enzymes. Sequences of PCR product from a few individuals from each location will also be obtained to confirm that the region being amplified is COI, and to compare sequences to each other and to results from restriction enzyme digestions.

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FOOD PREFERENCE STUDIES OF THE JAPANESE SHORE CRAB (HEMIGRAPSUS SANGUINEUS) FROM WESTERN LONG ISLAND SOUND

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Key Words: Japanese shore crab, food preferences, predator, Long Island Sound

The Japanese shore crab (Hemigrapsus sanguineus), a recent introduction to the Atlantic coastline, has been extending its range since its first recorded appearance in Cape May, New Jersey in 1988 (Williams & McDermott, 1990). Breeding Populations of H. sanguineus are now well-established in western Long Island Sound (pers. observ.) and its appearance has been documented at least as far north as the Cape Cod Canal (Lafferty & Kuris, 1996). Very little is known about the ecological impact this invader is having on the indigenous biota, but indications are that it could be significant. This study presents preliminary information on the food preferences of the Japanese shore crab in western Long Island Sound based on gut content analyses and food choice experiments conducted in the laboratory.

Pairwise choice experiments on four of the most common intertidal macroalgae in western Long Island Sound indicate the following preference hierarchy: Enteromorpha ssp. > Chondrus crispus > Ulva lactuca > Fucus vesiculosus. Crab algal consumption rates do not appear to be a function of crab size (carapace length). Experiments designed to investigate possible predatory habits of the Japanese shore crab, demonstrated that in addition to feeding on macroalgae, H. sanguineus will prey on a variety of bivalve seed, including Mya arenaria, Mercenaria mercenaria and Crassostrea virginica. These findings support the conclusion that the Japanese shore crab is omnivorous in habit and may represent the latest addition to a growing list of bivalve seed predators along the east coast of the United States.

Gut content analyses of wild-caught crabs were also performed on H. sanguineus and the two most common co-occurring species of mud crabs. (Eurypanopeus depressus and Panopeus herbstii) to determine degree of dietary overlap with the Japanese shore crab. Macroalgae were found to make up a large part of the gut contents of both H. sanguineus and E. depressus, suggesting that these two species may be competing for similar food resources, whereas P. herbstii guts contained large amounts of barnacle shell fragments indicating that they focus primarily on animal food items.

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HOW AND WHEN TO PROTECT NATIVE SPECIES FROM EXOTIC INVADERS: LESSONS FROM A PREDICTIVE MODEL

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Key Words: bottom-up effects, community linkages, estuaries, local extinctions, mathematical modeling, monitoring, mudsnails, predictions, relative importance, top-down effects

The exotic mudsnail, Batillaria attramentaria, was introduced to the West Coast of North America in the early part of this century with aquaculture imports of Crassostrea gigas, and has been displacing the native mudsnail, Cerithidea californica. Using data from detailed experiments on these species, we parameterized a model that predicts long term outcomes of the two snails in computer simulations. Quantification of our model from a real system grounded the model in reality and also allowed us to test hypotheses not amenable to field manipulations. We first tested the relative importance of top-down vs. bottom-up effects in driving the invasion of Batillaria. Such an analysis pinpoints the key pathway through which the exotic species achieves the majority of its impact, and also suggests pathways of intervention that will be most successful in controlling or delaying the impact of the exotic species. Results indicate that, for this specific system, exploitative competition is an extremely strong pathway of interaction between the snails and is therefore the link that needs to be broken to hinder the invasion. Secondly, to determine the earliest point that a monitoring program could detect the impact of the invader in the native system, we tested many response variables of the system at the community, population, and individual levels. Examination of these variables over hundreds of simulation replicates indicated that no response variable was able to predict the ultimate demise of the native species until after the presence of the exotic species and its effect on the native species was essentially irreversible. Such a finding suggests drastic implications for how we should generally view monitoring programs and risk assessment analyses.

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BIOLOGICAL TEST RESULTS FROM THE GREAT LAKES BALLAST TECHNOLOGY DEMONSTRATION PROJECT

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Key Words: ballast water, filtration, nonindigenous species introductions, plankton, pathogens

Three levels of filtration were tested for effectiveness at screening fresh and salt water organisms from the ballast water of ships. The three screen sizes (25 um, 50 um, and 100 um) were evaluated aboard two experimental platforms -- an operating commercial vessel in the fall of 1997, and a stationary barge in the fall of 1998 -- at a flow rate typical of Seaway-sized ocean-going ships (1200 gallons per minute). The host ship, the M/V Algonorth, owned by Algoma Central Marine, plies the Great Lakes/St. Lawrence System allowing tests in both fresh and salt water. The ship-board experimental platform consisted of the filter units and a pump mounted on the deck with piping to matched control and test upper wing ballast tanks. The stationary barge platform was docked at the Seaway Port Authority of Duluth in Duluth/Superior Harbor, and consisted of the same filter units and pump with piping to three identical catchment tanks of 175 gallons each with bottom outlets. Biological effectiveness was measured through comparing zooplankton, phytoplankton and microbial concentrations with and without filtration treatment. Plankton samples were collected using plankton nets. Whole water samples were collected to examine chlorophyll and microbial content. The biological effectiveness experimental design and methods will be summarized. Test results for both planktonic and microbial organisms will be reported. The presentation also will include a discussion of lessons learned regarding experimental design and test procedures.

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WHITHER EXOTICA OCEANICA?: THE SCIENCE AND MANAGEMENT OF MARINE INVASIONS IN THE 21ST CENTURY

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In terms of broad subscription, the science of marine invasions is no more than 10 years old but, as with all sciences, huge demands are now placed upon it to be robustly predictive. Prediction can be found down several paths, including synthesis and experimentation. Relative to synthesis, because we have so few rigorous regional assessments of bioinvasion diversity, we suffer from a Swiss cheese view of invasion ecology, with far too many holes to produce broad compelling predictions. Critical to the production of such assessments is to attack taxonomic illiteracy -- to revitalize the ability to recognize and identify marine organisms, an ability which is the sine qua non of all ecology and evolution. Critical to the analysis of such assessments will be the resolution of "correction" factors that take into account the profound differences in regional data sets. Relative to experimentation, vastly more effort must be placed on both autexperimental and synexperimental work. Fundamental to all invasion science is a need to be far more rigorous and forthright relative to such concepts as the "effects" of invasions (both in general and relative to individual species), which invasions are "successful" and "unsuccessful" and when invasions will occur (the "Ascidiella Paradox"), the role of "disturbance" in mediating invasions, the reality of selecting "top" invaders, vector complexity, isolation genetics, the geographic origins of specific invaders coupled with the antiquity of invasions (the ubiquity of pre-science shiprints), biases in the recognition of microscopic invasions, the real economic costs of invasions, and the "management" of established invasions. In short, invasion science must become far more quantitative and experimental. Finally, the importance of invasions in coastal community ecology and evolution needs to be seen as a more integral and fundamental element of change in the sea.

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THE ECOLOGY OF THE JAPANESE SHORE CRAB (HEMIGRAPSUS SANGUINEUS DE HAAN) AND ITS NICHE RELATIONSHIP TO THE GREEN CRAB (CARCINUS MAENAS) ALONG THE COAST OF CONNECTICUT, U.S.A.

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Key Words: Japanese Shore Crab, Green Crab, interspecific competition, and primary prey species, niche habitat, sediment selectivity

The Japanese Shore Crab (Hemigrapsus sanguineus de Haan) was first introduced to Atlantic waters through ballast water on September 24, 1988 in Cape May, New Jersey. Since then, Hemigrapsus sanguineus has spread at an alarming rate and has become well established on the Atlantic coast. Hemigrapsus sanguineus is now extremely abundant on the Connecticut coastline. H. sanguineus is thought to exploit the different but overlapping habitats on cobble and boulder shores in rocky intertidal habitats (Fukui 1988). In areas where Carcinus maenas (the Green Crab), used to be abundant H. sanguineus is the dominant species and few Carcinus maenas are found. This study focuses on the relative abundance, distribution, and feeding habits of Hemigrapsus sanguineus. Principle prey species for each size class of Hemigrapsus sanguineus was evaluated through stomach content analysis, and competition between these crabs and other indigenous crab species for niche habitat through sediment selectivity was evaluated. The introduction of nonindigenous species and their effects on native habitats is an area of growing concern as commerce and shipping increases. Little is known about this topic especially for marine habitats. This study will provide important base-line data and possible management strategies for future studies concerning Hemigrapsus sanguineus.

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WEST COAST BALLAST MANAGEMENT EDUCATION PROGRAM

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Project Period: March 1, 1998 - August 1, 2000

This project will provide an outreach program to educate 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 three overall objectives of the project are as follows: (1) to provide education on ANS and ballast management issues for the maritime industry, resource agencies, and the general public, and to demonstrate the key role of preventing introductions of exotic species (and the difficulties and costs associated with post-invasion control), (2) to educate the maritime industry about ballast management practices and technologies, and to facilitate 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 to provide an alternative to open ocean exchange. The project will be comprised of five major components:

(1) A general education publication on West Coast ANS and ballast management issues. The publication will be provided to a variety of audiences including the West Coast and Pacific Region shipping industry, the general public, and natural resource professionals. The brochure will be utilized for uses ranging from general education to assisting natural resource professionals with identification of exotics.

(2) A series of eight video-conferenced educational forums to increase industry awareness and knowledge of ballast management issues. Forums will be one-half day events where individuals involved with the ANS research and the development of ballast management or ballast technology approaches will be invited to provide a presentation to representatives of the shipping industry. Locations of the forums will be rotated between major West Coast ports in California, Oregon, Washington, Alaska, and Hawaii, and video-conferencing will be provided to allow for real-time participation by industry members who are unable to attend the meeting on-site.

(3) The first biannual newsletter and website focused on ballast management and West Coast ANS issues. The newsletter will provide summary proceedings from the project forums, as well as current information on nationwide ballast technology and management research, and West Coast ANS issues. The project web site will contain the newsletter, a current article bibliography, announcements, and linkages to other web sites. Additional general outreach will be pursued through providing articles and announcements to existing ANS and maritime publications and websites.

(4) The formation of an industry working group which will provide a basis for initiation and funding of future West coast ballast management demonstration projects.

(5) Evaluations conducted for all project activities, and a final report which will summarize the response of project audiences to outreach methodologies, and discuss future needs for ballast water technical assistance and outreach.

This paper will provide an overview of the project, and our project outcomes to date.

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SELECTION OF NATIVE AND NONINDIGENOUS GAMMARIDEAN AMPHIPODS (COROPHIUM SP.) BY JUVENILE ENGLISH SOLE (PLEURONECTES VETULUS)

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Key Words: prey selection, amphipod, juvenile fish, experiment

Experiments were conducted to test for native and nonindigenous prey selection by juvenile English sole (Pleuronectes vetulus - native to the West coast of North America). Prey included native amphipods (Corophium salmonis and C. spinicorne) and Northwest Atlantic amphipods (C. acherusicum and C. insidiosum). Single-species and mixed-species predation experiments were utilized in tanks containing sand or mud substratum. Single-species prey consumption in sand substratum was higher for C. spinicorne and C. acherusicum than for C. insidiosum and C. salmonis. Mixed-species prey selection on nonindigenous species in mud substratum and on C. acherusicum in sand substratum was greater than on native amphipods. Predation was greater in sand substratum than in mud substratum on all species but C. insidiosum. No sex-selective predation occurred on any species in either substratum type. Prey size selection was suggested for C. acherusicum in both single and mixed species experiments. Interspecific prey selection may have been affected by water visibility, substratum type, prey exposure, and species composition of the prey population.

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CLIMATE AND NONINDIGENOUS PERACARIDAN CRUSTACEANS IN EASTERN PACIFIC ESTUARIES

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Key Words: introduced species; Northeast Pacific; estuaries; global climate; risk analysis; Crustacea; Peracarida

Prolific invasions of northeastern Pacific estuaries by nonindigenous species (NIS) fit a global pattern in which the majority are indigenous to the western sides of the Pacific and the Atlantic. Within the Northeast Pacific, NIS numbers decline with latitude and few native species have invaded western ocean estuaries. Seasonal climate patterns of the northern hemisphere between 25 and 60o N. Lat. are assessed from sea surface temperature and salinity at the origins and at the destinations of common peracaridan crustacean NIS. The regional and global patterns of introductions coincide with variations in climate. Annual sea surface temperatures vary little in the Northeast Pacific relative to those of western ocean coasts and, below 50o N. Lat., low salinities occur in the coldest months rather than the warmest months. Introductions occur only in the range of climate conditions within which species evolve. The proliferation of introductions to the Northeast Pacific may result, in part, from the broad diversity of other climates that encompass the narrow range of climates in the region. Similarly, introductions of native species from the northeast Pacific to other regions may be rare because of the broader range of climate conditions they must endure there. The south to north decline of northeast Pacific NIS coincides with fewer species introductions occurring where greater annual variations in temperature and low summer salinities occur.

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POTENTIAL IMPACT OFTTHE INTRODUCED BRYOZOAN, MEMBRANIPORA MEMBRANACEA, ON THE SUBTIDAL SNAIL, LACUNA VINCTA, IN THE GULF OF MAINE

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Key Words: Membranipora membranacea, Lacuna vincta, Laminaria spp.

Recently, several introduced species have become established in benthic communities in the Gulf of Maine. These include the bryozoan, Membranipora membranacea. The overgrowth of Membranipora on kelps (Laminaria spp.) has a negative effect on the health of kelps, and may also have an effect on other marine organisms including Lacuna vincta that lives and feeds on kelps. To examine the potential impact of Membranipora on Lacuna populations, an experiment to determine the growth rate of Lacuna fed on kelps with and without Membranipora was undertaken. Lengths of Lacuna were measured every week for one month. In addition, field samplings were conducted in different depths of water to compare densities, lengths, and the number of egg masses of Lacuna on Laminaria spp. with and without Membranipora. The estimation of percent cover of Membranipora on Laminaria spp. was also determined. The results suggest that Membranipora may play an important role on Lacuna population dynamics.

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STATUS OF INVASIONS AND POLICY RESPONSE ON THE U.S. WEST COAST

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Key Words: Biological Invasions, Ballast Water, San Francisco Bay

Over the past 20 years, a rapidly accumulating body of knowledge has demonstrated that invasions by non-native organisms threaten the aquatic flora and fauna in the world's coastal regions and the human activities and economies that depend on them. Intensive research in the San Francisco Bay Estuary has provided data on striking alterations in biodiversity and ecosystem functioning. Over 230 exotic species, including protozoans, plants and animals, have become established in this estuary in salt-water and fresh-water habitats within the reach of the tides. Exotic organisms dominate several habitats, in which they account for 40% to 100% of the common species and sometimes over 90% of the number of individuals and total biomass. Furthermore, the rate of invasion has been dramatically increasing, from an average rate of less than one new species a year before 1960, to nearly four new species established each year since 1960. Other West Coast estuaries have been invaded to a lesser, though substantial, degree. Organisms introduced into one estuary may be rapidly spread to another by either natural mechanisms or human activities. For example the European green crab, Carcinus maenas, arrived in San Francisco Bay by 1990 and had spread to estuaries from Morro Bay, California to Grays Harbor, Washington--a range of around 900 miles--by 1998.

While estuaries, bays and harbors have been the most affected areas, exotic species may also threaten marine habitats on the open coast. A New Zealand sea slug (Philine auriformis, although there may be more than one species involved) that arrived in San Francisco Bay by 1992 has spread both to other central California bays where it has become very abundant, and to sandy bottom on the outer coast where it is sometimes now the most commonly collected sea slug all the way to southern California. A yet-unnamed South African sabellid worm that parasitizes abalone, and threatens many other types of marine snails in rocky habitats, has been released and continues to be released by abalone farmers, and may have become established in at least one site. These developments are particularly alarming because, until quite recently on the West Coast, waters of the open coast were virtually untouched by biological invasions.

Over the years, exotic organisms have been transported to the West Coast by a variety of activities. Probably the most important mechanism at present is the release of exotic organisms in discharges of ships' ballast water. The introduction and passage of the National Invasive Species Act in 1996 provided a golden opportunity to begin controlling ballast water discharges. Unfortunately, the law that resulted made it officially voluntary for ships to do anything about their ballast water throughout most of the United States. Thus, while it is a crime for ordinary citizens to release exotic species, ships are allowed to routinely dump enormous numbers of exotic organisms into the nation's waters, without monitoring or regulation.

In frustration, citizens have taken steps to regulate ballast water at the state and local level. In the last two years petitions and administrative actions to regulate ballast water discharges (which have prepared the way for litigation, should that prove necessary) have been initiated or supported by environmental groups, fisherman's associations, water districts and

regulatory agencies in the West. Thus far these actions have been pursued under sections of the federal Clean Water Act, Endangered Species Act or National Environmental Policy Act, or under state water quality or environmental mitigation laws. State fish and game and coastal protection laws, and state and federal restrictions on the importation of harmful species may offer additional avenues for action. Increasingly, however, the developing consensus is that ballast water is fundamentally a water quality problemó a waste discharge of a biological pollutant that should be regulated through a discharge permit system just as chemical pollutants are.

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PANEL DISCUSSION: PREVENTION VS. CONTROL OF BIOLOGICAL INVASIONS

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If we respond to the problem of biological invasions by focusing on controlling exotic organisms after they have been introduced into the environment, rather than on preventing their arrival and release in the first place, then we will have committed ourselves to failure. For example, there are on average at least four new exotic species arriving and becoming established in the San Francisco Bay Estuary each year, with over 230 exotic species now established. Within this same region, despite considerable expense and effort, there are control efforts underway for only seven species, all of them aquatic or marsh plants. For only one of these has a substantial level of control been achieved, and even that is intermittent. In general, control efforts can be difficult and expensive, can impose collateral damage or risk to the environment, and often don't work. They sometimes also generate civic strife: efforts to control exotic fish in California and exotic cordgrasses in Washington have lead to lawsuits, public protests and even arrests. In any event, we cannot possibly design, fund and implement control efforts fast enough to deal with the flood of exotic species arriving in our coastal waters.

With any serious effort we ought to be able to reduce the rate of introduction substantially. Currently, ballast water discharges are entirely unregulated in most of the United States; the aquarium, pet, and ornamental plant trades can freely import virtually all types of aquatic animals and plants, except for a small list of prohibited species; and many state agencies that are generally thought to be responsible for protecting native wildlife are busy promoting the expansion of aquaculture and mariculture, often without adequate safeguards to prevent the importation and release of exotic pests, parasites and diseases of fish and shellfish. Substantial gains could be made (with far better benefit/cost ratios than any control effort) by implementing common sense measures to regulate the importation and release of exotic organisms by these activitiesó including some measures that have been advocated by biologists and resource managers for decades.

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BOTRYLLID ASCIDIANS: FEW INVADERS OR MANY?

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Key Words: botryllid ascidian, species identification, genetic markers, life-history variation

Successful invasions of botryllid ascidians have been documented worldwide both recently and over the past 50-100 years. Ascidians, including botryllids, are now recognized as important invaders overtaking fouling communities and interfering with bivalve culture. What are the sources of these invasions, how many species are involved, and how might these invasions be controlled? These questions have not been easily answered due to problematic taxonomy for many ascidians including the botryllids. Molecular identification of problematic taxa, by comparing known voucher specimens from potential source populations with specimens from invading populations, is a promising technique for invasion tracking. Here, I show that genetic markers such as small ribosomal subunit and mitochondrial cytochrome oxidase DNA sequence data may be used to distinguish species of botryllids. Genetic information on North American botryllids on both coasts reveals more distinct species than previously understood from morphological characters. Behavioral and life-history variation between populations has raised the possibility of rapid differentiation or plasticity in introduced populations. I discuss multiple character approaches to distinguishing botryllid species including methods for collecting and preserving useful voucher specimens. Careful study of botryllid invasions should answer questions about mechanisms of invasion for a diversity of taxa with limited natural mechanisms of dispersal.

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USING PUBLIC OUTREACH AND EDUCATION AS A MEANS OF PREVENTION AND CONTROL OF NIS INTRODUCTIONS

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Key Words: public education and outreach, non-indigenous species

The introduction of non-indigenous species into the coastal waters of the Pacific Northwest poses a serious economic and environmental threat. Adverse impacts are of increasing concern to resource managers, the aquaculture industry, non-governmental organizations and concerned citizens. Recognition that invasive species can affect fisheries, waterways, public and private facilities, as well as the functioning of natural ecosystems, is increasing.

An informed and educated public is widely recognized as the cornerstone of effective prevention and control of aquatic nonindigenous species (Jensen 1998). To achieve this end, it is essential that information/education efforts convey up-to-date and accurate facts that are appropriately targeted and offer a consistent message. Washington Sea Grant Program has begun developing a series of NIS educational products in collaboration with the State of Washington, the National Estuary Program, the U.S. Fish and Wildlife Service, and the Georgia Basin/Puget Sound International Task Force. The goal of these educational products is to increase awareness of NIS and their potential impacts on the environment and economy.

Public awareness is a realistic and cost-effective method to prevent or slow the introduction of NIS. Although the need to regulate intentional introductions of non-native species has long been recognized, we are only beginning to understand some of the pathways that transport new species into coastal and inland waters. Many of these pathways cannot be regulated. Since a single boat carrying zebra mussel or a boat trailer with Brazilian Elodea tangled on it can bring an infestation to a watershed, it is only with the aid of an educated public that we can block the introduction of NIS through certain of these pathways. Yet the concept of NIS is often unknown to large sectors of the public. Greater public awareness of the problem and how individual actions play a role in the transmission of NIS is essential to slowing or preventing introductions.

Among the educational products being produced by the Washington Sea Grant Program are:
A 20 pp. booklet entitled "Bio-invasions: Breaching Natural Barriers," which explains in simple, clear terms the threat of non-native aquatic species and potential impacts on the economy and on the environment; Fact sheets on common pathways for aquatic NIS introductions and the European green crab (Carcinus maenas);
A full color identification card for the European green crab, including features that distinguish them from similar-looking native crabs;
A training workshop on identification of the European green crab for volunteer groups, industry workers, tribes and agencies;
A poster and T-shirts introducing the concept of invading species with an eye-catching design and a simple explanation of what invading species are and how they can be transported; and
A card for distribution at pet stores and other venues explaining why aquarium hobbyists should not release pets or plants into the wild and suggesting alternatives to dumping.

Strategies for targeting appropriate audiences, determining vehicles and delivery mechanisms for reaching those audiences, and evaluation methods for determining their effectiveness will be discussed.

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SCALE-DEPENDENT EFFECTS OF AN INTRODUCED, HABITAT-MODIFYING MUSSEL IN AN URBANIZED WETLAND

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Keywords: Habitat modification; facilitation; scale-dependence; mussel mats

Nonindigenous species capable of physically altering habitats can have a wide variety of effects on resident biota. One such introduced habitat modifier (or ecosystem engineer) is the small mytilid mussel, Musculista senhousia. The effects of this invader, which can form high-density mats on the surface of soft sediments, appear scale-dependent. At larger scales, surface-dwelling, suspension-feeding clams are competitively inhibited. At smaller scales, however, the mussels benefit a variety of resident biota. These facilitory effects are mediated primarily by the physical architecture provided by the mats, although the activities of living mussels influence some species. The effects observed for M. senhousia appear to be general for a variety of aquatic and terrestrial invaders capable of altering the physical nature of habitats, and include positive effects of invaders that increase habitat complexity.

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THE SABELLID PEST OF ABALONE: THE FIRST ERADICATION OF AN ESTABLISHED INTRODUCED MARINE BIOINVADER?

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Key Words: eradication, marine pest, sabellid, polychaete, abalone

Once a marine invader has become established its subsequent control has been met with little more than fatalism. However, as illustrated by the case of the sabellid worm, such an outlook may not be warranted. A previously unknown species, this sabellid polychaete arrived as a contaminant on imported South African abalone and was initially contained in California abalone mariculture facilities. The sabellid infestation caused shell deformation and slowed growth of the cultured abalone, resulting in great economic losses to the industry. However, having broad host specificity, its potential impacts are not confined to just abalone; it can readily infest many other native California gastropods. We detected an established population at an intertidal site near Cayucos, California in 1996. To mitigate the impact of this introduced marine pest at this site and prevent or slow its geographic spread, we proposed an eradication program based on the epidemiological theory of the threshold of transmission. That is, if the density of transmissive stages and the density of highly susceptible hosts are reduced below the replacement transmission rate, successive generations of the pest will damp out. Specifically, our eradication program includes three components: (1) prevention of further release of adult worms from the facility, (2) reduction of the adult pest population and (3) reduction of the most susceptible native host population. This three-fold approach is unique in that it not only targets the pest, but also a component of the pestís life cycle - the host - which is required for continuance of the established population. The eradication program has been implemented in collaboration with the associated mariculture facility and the California Department of Fish & Game. Using transect surveys and mark and recapture studies, we have monitored the success of the eradication efforts. April 1998 surveys found new infestations had, at least temporarily, been eliminated. This potentially successful eradication program suggests the need for - and has depended on: (1) early detection, (2) cooperation between commercial interests, regulatory agencies and pest control scientists, (3) rapid response (avoidance of analysis paralysis), (4) development of a control strategy with a theoretical basis, (5) persistent efforts beyond the point where the situation has merely improved and (6) monitoring of eradication efficacy through use of sentinel habitat experiments. The current status of our eradication program and implications for use with other introduced species will be discussed.

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PATHWAYS AND MANAGEMENT OF AQUATIC NONINDIGENOUS SPECIES IN DELAWARE

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Key Words: management, Delaware, pathways

The introduction of aquatic nonindigenous species has the potential to cause significant environmental and economic harm in Delaware waters, as it has throughout the world. To date, the extent to which Delaware waters are invaded by nonindigenous species has not been assessed. Likewise, an examination as to effectiveness of Delaware's current management framework to prevent and control nonindigenous species has yet to be conducted.

Through literature searches and interviews with Delaware natural resource officials, approximately forty (40) nonindigenous species were found in Delaware's fresh, brackish, and marine waters. Six of these were considered nuisance species, costing the State a significant amount in control efforts. Of the five principal pathways of introduction highlighted in the literature (stocking programs, shipping, recreational boaters and anglers, aquarium and ornamental releases, and aquaculture), all five were likely responsible for some introductions into Delaware waters. Ballast water discharges and recreational boating and angling pose the greatest potential risk for introducing nonindigenous species into Delaware, although no one pathway appeared to be especially dominant. This rough assessment was based on the number of known harmful species likely being introduced (e.g., the number of ships discharging ballast water potentially containing harmful nonindigenous species into Delaware Bay).

Interviews were conducted with personnel in six state-level nonindigenous species management programs (Chesapeake Bay, Lake Champlain, New York, Michigan, Minnesota, and Puget Sound). Lessons drawn from these current efforts might prove helpful in devising a management strategy for Delaware. The majority of programs focused exclusively on aquatic species (rather than an all encompassing terrestrial and aquatic species approach) and utilized education as the primary management tool. Stakeholder inclusion was a key component of the development process. Many policies became stymied by low recognition of the issue, leading to deficiencies in staff and funding, which in turn adversely affected implementation.

Effective state-level nonindigenous species management is hampered by five shortcomings: inadequate baseline information, insufficient authority, delays in response time, lack of an institutional framework, and low levels of support for action. I addressed these deficiencies through five corresponding policy prescriptions. The proposed measures set forth to close loopholes in the current regulations, establish a nonindigenous species monitoring program, create a mechanism to coordinate management actions, and call for education targeted at the responsible parties.

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DETERMINING THE PATHWAYS OF MARINE BIOINVASION: GENETICAL AND STATISTICAL APPROACHES

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Key Words: multilocus, genetic, DNA, population, source

Advances in genetic technology have enabled biologists to reconstruct the history of populations, their evolutionary relationships and geographical origins. Such information is essential in understanding the biology of invasions and in designing successful management responses. Unfortunately, the wholesale transfer of 'traditional' population genetic methodology to identify the origins of marine bioinvasions is inappropriate. By definition, invading populations are characterized by their rapid and recent range expansion. This has two important genetic consequences: (i) genetic diversity is often very low due to the bottlenecks in population size associated with the founding of new populations, and (ii) evolutionary relationships among genes may bear no relation to the history of populations. These characteristics of invading species limit our ability to reconstruct their geographic history. Here, we evaluate the genetic markers and statistical methods currently being used to determine the invasion pathways of species of economic importance in agriculture and fisheries. Analyses of molecular genetic data fall into two categories: those based on phylogenies, and those based on frequency differences of genetic markers. Here, we describe these two approaches and outline the conditions under which they are appropriate and useful in marine bioinvasions. Of critical importance are factors such as effective population size, time since the separation of populations, magnitude of gene flow among populations, and rates of genetic recombination. Despite its intuitive appeal, a phylogenetic analysis of genotypes relative to geography (known as phylogeography) is often inappropriate for tracing the history of very recently founded populations. Although phylogenies in such situations are useful for determining the homology of alleles and understanding patterns of mutation and recombination, statistical analyses of multilocus genotypes are required to resolve historical relationships for many invading populations.

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CHARACTERIZATION OF BACTERIAL ASSEMBLAGES IN SHIPS' BALLAST WATER

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Key Words: microbial ecology, Biolog, Chesapeake Bay, ballast water

Microbiological studies of ballast water will help us understand the transfer, dynamics, and invasion potential of microorganisms carried by ships (see related abstracts by Rawlings et al. and Drake et al.). We have begun to characterize the ballast water bacteria in samples collected from ships arriving in the lower Chesapeake Bay. Such characterization is based on interpreting substrate-utilization patterns. We inoculate ballast-water samples into Biolog microtiter plates (Biolog, Inc., Hayward, CA), which contain 95 different carbon substrates in separate wells. These wells, and a control well, also contain a tetrazolium salt that indicates (via color development) microbial utilization of a substrate. The rate and extent of a substrate's utilization is determined through time-series measurements of a well's optical density.

There has been a wide range of response among the ships (n=13) sampled to date; clearly the bacterial assemblages of ballast waters vary considerably. In more than half the cases, however, there are commonalities in response that may be influenced by duration of voyage, source water, and exchange history. In addition to its furthering our understanding of ballast-water ecology, this technique potentially has uses for routine monitoring of arriving ships and evaluating the efficiency of water exchange or filtration.

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GEOGRAPHIC VARIATION IN THE FREEZING TOLERANCE OF THE RIBBED MUSSEL, GEUKENSIA DEMISSA

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Key Words: Freezing tolerance, Geukensia demissa, Introduced Species, Supercooling

The Ribbed Mussel, Geukensia demissa, native to tidal marshes on the American Atlantic coast, was accidentally introduced to the American Pacific coast over 100 years ago. Mussels native to the Atlantic Northeast (NE) coast experience wide variation in seasonal temperature, including subfreezing winter conditions. To combat potentially lethal winter freezing temperatures, NE mussels use a variety of seasonally induced biochemical and physiological adjustments to tolerate ice in their extracellular fluids. Pacific coast mussels, however, are not exposed to freezing temperatures experienced by their NE counterparts. It was hypothesized that Pacific coast mussels may have lost the adaptive ability to withstand these freezing conditions. I examined the geographic and seasonal variations in the response of Geukensia to subfreezing conditions. Mussels from Connecticut and Southern California were exposed to a variety of subfreezing temperatures. Survival, supercooling point, and final temperature were used as indices of response to freezing. For all indices measured, in a given season there were no significant differences found between California and Connecticut mussels in freezing response. However, a significant difference existed between summer- and winter-acclimated mussels: both California and Connecticut winter-acclimated mussels had significantly different supercooling points ($df=1$, $F=6.37$, $p<0.05$) and final temperatures ($df=1$, $F=24.6$, $p<0.01$). These results support previous literature on changes in seasonal cold tolerance. The fact that mussels from California did undergo seasonal acclimation, despite the lack of strong seasonal temperature cues, lends itself to the role of other environmental cues in triggering winter acclimation. Introduction to the Pacific coast has not resulted in a loss of freezing tolerance of G. demissa.

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CONSIDERATIONS IN THE DEVELOPMENT OF NEW RISK ASSESSMENT TECHNIQUES FOR AQUATIC NUISANCE SPECIES: THE ROLE OF TRANSPORT VECTORS IN RISK ASSESSMENT

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Key Words: risk assessment, introduction, pathways, transport vectors

Aquatic nuisance species (ANS) are a growing concern to natural resource and environmental managers. The alarming rate at which nonindigenous species are being both introduced and established is a driving force behind increasing awareness of and proposed actions aimed at ANS issues. However, it is not feasible to address every invasive species concern thus these issues must be prioritized. One conventional method by which land managers have ranked invasive species is via risk assessment. Before managers dealing with ANS rush to adopt these methodologies, we suggest that it is imperative that these tools be evaluated with special attention paid to their applicability in the aquatic realm. Do these risk assessment protocols produce answers that are important to ANS scenarios? That is, are we interested in the same questions that land managers need answers to or do ANS differ fundamentally from terrestrial invaders? Most terrestrial risk models for invaders follow a species oriented predictive risk assessment methodology. We suggest that in the aquatic realm the pathways or transport vectors by which ANS are introduced represent an important step in the invasion process, and one that is neglected in conventional risk assessment. We review risk assessment methodologies currently in use and demonstrate how pathways can be incorporated into these procedures to the benefit of managers concerned about both specific invasive species or general ANS issues.

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INVENTORY OF MICROBES IN BALLAST WATER OF SHIPS ARRIVING IN CHESAPEAKE BAY

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Key Words: microbes, Chesapeake Bay, ballast water

Perhaps the least-studied aspect of marine bioinvasions is the transfer of nonindigenous microbes. Given the high densities of naturally occurring bacteria, viruses, and phytoplankton in coastal waters, it seems inevitable that high numbers of microorganisms are transported globally via ballast water. As a first step in evaluating the rate and extent of this transport, we boarded vessels, primarily colliers arriving in Norfolk, VA and Baltimore, MD, to quantify the microbes present in their ballast water tanks. We used epifluorescence microscopy to measure abundances of bacteria and virus-like particles and incorporation of DNA precursors to determine bacterial production rates. We also measured the ballast watersí temperature, salinity, and concentration of chlorophyll a. Direct counts of bacteria and virus-like particles ranged over two orders of magnitude, from 107 - 109 cells per liter and 108 - 1010 cells per liter, respectively. Similarly, bacterial production rates, expressed as incorporation of tritiated thymidine into DNA, varied broadly, from 0.40 - 13 picomoles per liter per hour. Chlorophyll a values ranged from 0.005 - 0.04 micrograms per liter. Relationships between hydrographic characteristics of ballast waters and microbial signatures will be discussed.

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FOUR CENTURIES OF BIOLOGICAL INVASIONS IN CHESAPEAKE BAY

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Key Words: Chesapeake Bay, biological invasions, historical survey, cryptogenic species, ballast water, ecological impacts Chesapeake Bay has been subject to biological invasions since the start of European colonization in 1609. In a comprehensive analysis of the historical patterns of invasion, we identified 160 nonindigenous species that now occur in tidal waters of the Chesapeake. These species represent 17 different phyla, including vascular plants and invertebrates to vertebrates and single-celled protistan pathogens. Invasions are documented from all regions and habitats of Chesapeake Bay. Source regions and transfer mechanisms have varied greatly over time and by taxa, and the rate of invasions has increased in recent decades. In addition to known invaders, the Chesapeake has a high proportion of cryptogenic species (i.e., those of unknown origin). Historical surveys and first records of many taxa are relatively recent, occurring well after possible transfer by European colonization. Of 800 species of benthic invertebrates and macroalgae in Chesapeake Bay that we have examined, 30% (237 species) also occur in Europe, suggesting that many unsuspected introductions exist. Today, multiple pathways for new invasions are still active in Chesapeake Bay. Shipping is presently the largest pathway for the transfer and release of organisms to the region. Two recent ballast-mediated invasions underscore the continued importance of this vector. Although invasions have had significant ecological and economic impacts in the Chesapeake, the consequences of most marine invasions remain unmeasured here and elsewhere.

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THE DISTRIBUTION AND CLASSIFICATION OF THE COLONIAL HYDROIDCORDYLOPHORA (PHYLUM CNIDARIA, CLASS HYDROZOA)

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Key Words: hydroids, range of distribution, taxonomy

Cordylophora is a colonial hydroid occurring in brackish and freshwater habitats. Records indicate that the distribution of this hydroid is expanding globally by rapid boat travel and ballast discharge. Cordylophora is becoming more common in freshwater habitats due probably to an increase in salts (chlorides) from runoff with road salts. Currently we are documenting the distribution of Cordylophora populations in several freshwater systems in the United States. Recently Cordylophora posed a problem to a local power plant and we were hired to curtail hydroid growth in pipes. Laboratory experiments using cultured colonies of Cordylophora indicate that temperature is most effective (compared to chlorine) in killing or curtailing hydroid growth. We are also beginning preliminary DNA analyses on various populations of Cordylophora to address a discrepancy of species identification found in the literature. DNA analyses (characterization of 16S rRNA) along with interbreeding experiments will assist in clarifying the taxonomic confusion currently existing for Cordylophora. Elucidation of the overall distribution patterns and genetic structure of various hydroid populations will assist in confirming or modifying the taxonomy and species composition of an organism that may be becoming a more visible invading species.

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GRAZING PRESSURE ON ENDEMIC AND INTRODUCED SUBSPECIES OF CODIUM FRAGILE

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Key Words: Codium fragile ssp. tomentosoides, urchin, grazing

This study compared the grazing pressure on the introduced, subtidal Codium fragile ssp. tomentosoides in the Atlantic Ocean to grazing pressure on the endemic, intertidal Codium fragile in the eastern Pacific Ocean. In laboratory experiments conducted on the Atlantic coast, the sea slug Placida dendritica consumed significant amounts of the algae but was not dense enough in situ in the Gulf of Maine or Long Island Sound during 1998 to affect populations of C. fragile ssp. tomentosoides. The sea urchin S. droebachiensis consumed C. fragile ssp. tomentosoides in single diet experiments in the laboratory but not in field transplants. In the Pacific (Friday Harbor, Washington) both S. droebachiensis and S. franciscanus consumed C. fragile in laboratory experiments, however S. franciscanus consumed significantly more C. fragile than did S. droebachiensis. Furthermore, preliminary results suggest that large urchins are more effective grazers on C. fragile than small urchins. In field experiments, C. fragile transplanted to S. franciscanus barrens were heavily grazed. These results suggest that grazing pressure from S. franciscanus is responsible for confining C. fragile primarily to low intertidal in areas in the eastern Pacific. In contrast, a lack of this grazing pressure in the Atlantic may have allowed C. fragile ssp. tomentosoides to spread to subtidal areas.

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MEASURING THE EFFICACY OF BALLAST WATER EXCHANGE

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Key Words: ballast water exchange, invasion rate

Ballast water exchange is being promoted nationally and internationally as a management strategy to (1) decrease the abundance of coastal organisms within shipsí ballast water and thereby (2) reduce the risk of future invasions by nonindigenous species. We are measuring the efficacy of two distinct exchange methods (Flow-Through and Empty-Refill) to remove organisms from ballast tanks across multiple ship types. Physio-chemical and biological tracers were used to estimate the effects of exchange on different components of ballasted communities. Preliminary results, based on salinity and Rhodamine dye tracers, indicate significant water mass exchange (>80%) for both Flow-Through and Empty-Refill methods, with the latter being more efficient. Further analysis of biological samples will test for variation in effects among taxa. Despite the apparent reduction in coastal organisms through exchange, a small percentage (but sometimes still a large number) of residual organisms can remain in exchanged tanks. The overall effect of ballast water exchange in reducing invasions therefore depends not only upon (a) the percent of vessels that exchange their ballast water and (b) the methods and results of exchange per vessel, but also (c) the relationship between supply and invasion rates. Although reduced inoculation densities should result in reduced invasion rates, the shape of this relationship is unknown. Thus, efficacy of exchange, or other management strategies, must be measured according to both rate of organism transfer and rate of invasion.

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THE "SILVER LINING" - THE ECONOMIC IMPACTS OF RED SEA INVADERS IN THE MEDITERRANEAN

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Key Words: economic impacts of invasions, Red Sea, Mediterranean, fisheries, prawns, jellyfish

Invasions by allochthnous species occur in aquatic ecosystems throughout the world, leading to significant, and sometimes severe, biological repercussions and economic effects. The opening of the Suez Canal initiated a remarkable faunal movement: hundreds of Red Sea species settled in the Mediterranean, forming thriving populations along the Levantine coasts.

Huge swarms of the invading nomadic jellyfish, Rhopilema nomadica, have appeared each summer along the southeastern Levant coast since the mid 1980's, and by 1995, reached the southeastern coast of Turkey and Cyprus. The massive swarms of these planktotrophs must play havoc with the meager resources of this oligotrophic sea, and when the shoals draw nearer shore, they impact fisheries, coastal installations and tourism. That same jellyfish shelters among its tentacles, the juveniles of a Red Sea carangid fish Alepes djedaba, an increasingly important catch.

Other abundant invaders are exploited commercially, constituting today nearly half of the trawl catches along the coast of Israel. Some commercially important invaders have outcompeted authochtonous species. A native penaeid prawn, Penaeus kerathurus, that supported a commercial fishery throughout the 1950's, has since nearly disappeared and its habitat overrun by the Red Sea penaeid prawns Penaeus japonicus and P. semisulcatus. From the southern coast of Turkey to Tunis, Red Sea penaeids have replaced P. kerathurus in prawn fisheries.

Though the expected outcome of invasion is reduction in diversity, we witness an invasion that increases diversity and has added new species to the local fisheries.

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EFFECTS OF THE INVASIVE SEAWEED SARGASSUM MUTICUM ON NATIVE MARINE COMMUNITIES IN NORTHERN PUGET SOUND, WASHINGTON

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Key Words: Sargassum muticum, epiphytic communities, invasive seaweed, species diversity

Sargassum muticum was introduced to the West Coast of the United States in the 1940ís and has since established itself as a persistent member of coastal communities from British Columbia to California. The efficient dispersal methods and fast growth of S. muticum allow it to effectively compete for space and light with native seaweeds. S. muticum reaches up to 3.5 m, forming large "trees" due to its extensive branching and buoyancy provided by floats. This study investigated the epiphytic communities associated with S. muticum to determine if the seaweedís presence affects the composition of shallow subtidal communities in northern Puget Sound.

The community that S. muticum supports differs from that associated with the native seaweed Laminaria saccharina, the seaweed most often displaced by the invading S. muticum. The S. muticum species community composition is dominated by five snails, one polychaete, four crabs, four caprellids, several other amphipods, two isopods, and two shrimp. The L. saccharina species community composition is dominated by one bryozoan, one scaleworm, and a variety of larger snails. Several species of polychaetes, bryozoans, and nudibranches associated with L. saccharina were never found associated with S. muticum. Unlike the seasonally stable community associated with L. saccharina, the community associated with S. muticum changes throughout the growing season (May through October), and with the local habitat. Individual S. muticum thalli also support more epiphytic biomass per gram of algal tissue than do L. saccharina thalli. The concentration of detritus and diatoms on the extensive thallus is then available to browsers. S. muticum is also a primary food source for grazers, including the snails, Lacuna vincta and L. variegata. The seaweed provides a refuge for several fish species and juveniles of both the red rock crab and the dungeness crab. In summary, the invasion of S. muticum changes the ecology of the coastal communities by allowing certain native species to dominate over others that are associated with the native L. saccharina.

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HULL FOULING AND BALLAST SEDIMENTS: THE IMPORTANCE OF VECTORS OTHER THAN BALLAST WATER IN TRANSPORTING NONINDIGENOUS MARINE SPECIES IN THE HAWAIIAN ISLANDS

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Key Words: ballast water sediments, hull fouling Hawaiiís status as a net importer of manufactured and raw materials tends to decrease the average amount of ballast water carried by commercial vessels arriving to ports in the area. Alternate vectors such as ballast water sediments and hull fouling can be of more importance in a port system with this operational dynamic. Ballast water sediments and hull fouling organisms are being collected randomly from commercial vessels arriving in Hawaii from foreign and U. S. mainland ports. Live analysis of all samples is performed and the ballast water sediments are further examined by culture methods to assay for phytoplankton species. Hull fouling samples and ballast sediments have yielded live, viable organisms like the barnacle Chthamalus proteus, which has been introduced into Hawaii. The findings to date for this study and historical data on hull fouling species reported in Hawaii will be presented.

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SURVIVAL RATES OF SPECIES IN BALLAST WATER DURING INTERNATIONAL VOYAGES. RESULTS OF THE FIRST OCEAN-GOING AND LAND-BASED WORKSHOPS OF THE EUROPEAN CONCERTED ACTION: "TESTING MONITORING SYSTEMS FOR RISK ASSESSMENT OF HARMFUL INTRODUCTIONS BY SHIPS TO EUROPEAN WATERS"

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Key Words: ballast water, sampling methods, survival rates, international co-operation

During the last decades ballast water discharges have increased throughout the world in most of the major ports. Discharge volumes are considerably higher in some areas and the probability of successful establishment of self-sustaining populations of exotic species is expected to increase with greater volumes of ballast water and reduced ship transit times. Ships have been recognized as a major vector for the introduction of nonindigenous and harmful organisms. Although many desk studies and ship sampling programs were carried out it is agreed that a lack of data on the survival rates during ship journeys exists. Sampling of vessels during voyages were carried out on a limited scale by several laboratories. Detailed formation on changing environmental conditions in ballast tanks and on the survival rate of species will assist to evaluate the risks of unintentional species introductions in the future. During a previous study, the survival of plankton organisms in ballast water tanks was studied by accompanying a container vessel on its 23 day voyage from Asia (Singapore) to Germany (Bremerhaven). Former ballast water investigations during ship journeys showed the decrease of specimens and the reduction of diversity according to the time of the ships voyage. As expected, the number of specimens decreased dramatically in one of the two investigated tanks. In the second tank the number of individuals of the harpacticoid copepod, Tisbe graciloides, increased from 11 specimens per 100 litre in the beginning to more than 1000 individuals in the end. An increase of specimens during ship journeys was never documented before. This new dimension of species transportation in ships ballast tanks indicates that ballast tanks may be incubators under special conditions and emphasises the risk of species transport with this vector. In the beginning of 1998, a Concerted Action Study, financed by the European Union, was launched dealing with e.g. the harmonisation of sampling methods of ballast water and documentation of survival rates of species during inter-oceanic and short term voyages. Various European sampling methods have been studied in order to assess their effectiveness qualitatively and quantitatively. First results showed that the effectiveness of these ballast water sampling methods varied from 95,8% to less than 5%. Furthermore, sea-going workshops will involve Concerted Action Partners and invited experts on a broad scale. In total 6 voyages quantifying the survival of organisms in ballast tanks will be undertaken. The applicability of the harmonised ballast water sampling method will be addressed on board. The initial results of two intercalibration workshops of ballast water sampling methods and two ocean-going workshops are discussed.

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THE RISK OF NONINDIGENOUS SPECIES INTRODUCTIONS TO PUGET SOUND, WASHINGTON THROUGH THE SHIPMENT OF LIVE BAIT

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Key Words: marine worms, aquatic nuisance species, pathways, Puget Sound, Washington, risk assessment

The shipment of marine bait worms from Maine for recreational purposes-a likely pathway for NIS introductions in other Pacific coast estuaries (Carlton, 1989; Cohen et al.,1995) is not presently regulated in Washington State. In order to assess the risk of NIS introductions to Puget Sound, Washington through this pathway, we surveyed users of the product and product suppliers. The surveys consisted of telephone interviews, visits to local live bait worm vendors and product inspection. We found no evidence that live marine bait worms were available through local vendors or of a local market for live marine bait worms. Therefore, we determined that the live bait worm trade does not appear to pose a threat to the Puget Sound region.

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OVERVIEW OF ECOLOGICAL AND EVOLUTIONARY CONSEQUENCES OF INVASIONS

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Our knowledge of how nonindigenous species influence ecological and evolutionary processes in marine systems is fragmentary in comparison with our understanding of terrestrial and aquatic systems. To characterize the state of our knowledge regarding the ecological and evolutionary consequences of marine invaders, I will highlight examples of studies that have measured the impacts of nonindigenous species on native populations, food webs, and ecosystem processes. I will also discuss examples of studies that have quantified the evolutionary consequences of marine invasions for native and nonnative species. My goal is to emphasize what I believe have been the most productive approaches to the study of ecological and evolutionary consequences of marine invasions and what will be the most fruitful directions for future actions.

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THE IMPACTS OF THE EUROPEAN GREEN CRAB ON MULTIPLE TROPHIC LEVELS IN CENTRAL CALIFORNIA

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Key Words: European green crab, ecological impacts, trophic levels

Using long-term data and experiments in both field and laboratory, we quantitatively examine the ecological impacts of the nonindigenous European green crab in a soft-substrate food web in Bodega Harbor, CA, USA. Our results show that significant direct effects of green crab predation--large reductions in green crab prey including bivalve molluscs and crustaceans--have occurred within two years of the invasion. These prey populations have remained at very low abundances for four years since the introduction of the green crab. Also, significant indirect effects of green crab predation--increases in non-prey including polychaetes and tube-building crustaceans--have also occurred within two years of the direct effects. These direct and indirect responses to green crab predation are rapid and are nearly concurrent given the time scale of sampling. However, reductions in invertebrate prey populations have not resulted in changes at the higher trophic level occupied by shorebirds in the Bodega Harbor system. We have found no reductions in the abundances of wintering shorebirds over the four years since the green crab invasion. Therefore, the timing of changes in the abundances of native species, whether directly or indirectly affected by the invading green crab, may be more a function of life-history and recruitment rate than of position in the food web.

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CRYPTOGENIC SEAWEEDS, SEAGRASSES, AND MARINE LICHENS IN PORT VALDEZ, ALASKA: WHO ARE THEY AND HOW DID THEY GET THERE?

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Key Words: seaweeds, seagrasses, marine lichens, marine algae, estuarine, cryptogenic, dispersal, biogeography, Port Valdez, Alaska

During a recent field and literature survey of marine and estuarine species introductions in Port Valdez, Alaska, a new checklist of the seaweeds, seagrasses and marine lichens of the area was prepared and examined for the presence of nonindigenous species. Although no unequivocal introductions were discovered, over half of the 115 species were found to be widely distributed: 32 occurred circumboreally and 28 had ranges that extended into the southern hemisphere. These widespread species, called "cryptogenic" by James Carlton, Williams College/Mystic Seaport, Mystic, CT because they have hidden origins, are thought to have a high probability of being anthropogenically introduced or misidentified in at least some parts of their range. Many of these taxa do have excellent natural dispersal capabilities. Of the 60 cryptogenic species reported for Port Valdez, 32 are known to survive unattached, and at least 27 have life histories that are ephemeral and frequently reproduce and/or fragment. However, nearly all also occur as fouling organisms on the hulls of ships, and recent studies have shown that the propagules of many can survive the now shorter entrainment times required for transport in ballast water across the North Pacific. It is likely that the broad ranges of these species have been created by both natural and anthropogenic means. Future ecological and taxonomic studies that employ field, molecular and morphological techniques should help to resolve the cryptogenic nature of these species and determine their native vs. introduced status in the areas that they inhabit.

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HABITAT AND PREY PREFERENCES OF VEINED RAPA WHELKS (RAPANA VENOSA) IN THE CHESAPEAKE BAY: DIRECT AND INDIRECT TROPHIC CONSEQUENCES

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Key Words: Rapana venosa, gastropod, Chesapeake Bay, habitat use, infauna, burrowing, hermit crab, Clibanarius vittatus

The recent discovery of Veined Rapa Whelks Rapana venosa in the lower Chesapeake Bay has ecological consequences beyond the obvious potential for predation on commercially valuable shellfish prey species (e.g., Crassostrea virginica, Mercenaria mercenaria. In the Black Sea and in their native Sea of Japan, Rapana have been reported primarily from hard bottom habitats. Adult Chesapeake Bay Rapana have been collected from both hard and soft bottom habitat. Laboratory observations indicate that adult Rapana prefer sand bottom and will burrow almost completely into the sand at water temperatures > 20 C (i.e., not overwintering behavior). Burrowing behavior by these large apex predators expands the potential suite of vulnerable prey items to include infaunal shellfish (e.g., Mya arensis, Ensis directus, Cyrtopleura costata. The presence of large (>100 mm) empty Rapana shells in Chesapeake Bay may enhance growth of the local hermit crab Clibanarius vittatus. Recent collections of C. vittatus from the Hampton Roads area indicate that these animals use empty Rapana shells as shelters and are reaching previously unrecorded sizes. The implications of abnormally large crustacean scavengers on Chesapeake Bay benthic epifauna (e.g., oyster spat) are discussed.

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PATTERNS OF RANGE EXPANSION, NICHE SHIFT AND PREDATOR ACQUISITION IN CODIUM FRAGILE AND MEMBRANIPORA MEMBRANACEA IN THE GULF OF MAINE

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Key Words: Codium, Membranipora, range expansion, niche shift, predators

Introduced species often undergo stages of expansion in range, niche breadth and the acquisition of predators as established species recognize a new food source. The alga Codium fragile and the bryozoan Membranipora membranacea illustrate these patterns in the Gulf of Maine. Codium became common in several protected areas in the early 1980"s and has continued to expand its distribution in such habitats. More recently, it has expanded to occupy exposed habitats and is now the dominant canopy species to 8m in both former urchin barrens and established form kelp beds in both protected and exposed locations. The saccoglossan Placida dendritica has become an important herbivore on Codium and appears to be causing a reduction in this alga in some protected sites. Membranipora first appeared at the Isles of Shoals in 1987 and has expanded its range throughout the Gulf of Maine, first as an epizooite on kelps and then on a wide diversity of algae, including arborescent, cylindrical algae such as Desmarestia. Over the last five years, the dorid nudibranch Onchidoris muricata has adapted to recognize Membranipora as a food source in the settling larval stage. This annual winter predator on dormant populations of Membranipora has the potential to significantly alter the impact of this competitively dominant encrusting species, particularly in the cooler northeastern portions of the Gulf of Maine. Patterns of expansion of habitat and interaction within the Gulf of Maine are discussed.

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IMPACT AND MANAGEMENT OF ESTABLISHED MARINE INVADERS IN NEW ZEALAND

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Key Words: New Zealand, Tasmania, Spartina, Undaria, eradication, site led control

Two case studies, the saltmarsh cord-grass, Spartina, and the Asian kelp, Undaria, illustrate internal management issues in New Zealand. Spartina, long established in numerous estuaries, dramatically changes estuarine habitat. Undaria, a relatively recent arrival, has become ecologically dominant in several harbours and in some areas has reached the open coast. Coastal shipping and the marine farming industry are rapidly dispersing Undaria throughout New Zealand. Both species are perceived as weeds by conservation agencies, and there have been attempts to eradicate them at sites of high conservation value.

In the case of Spartina, the eradication attempts have been largely successful with no significant reinvasion after ten years. Recent attempts to eradicate Undaria from Stewart Island in southern New Zealand appear to have been less successful, as have attempts to eradicate the plant at a site in neighbouring Tasmania.

Both examples illustrate the need for understanding impacts and invasion mechanisms to provide a good basis for making management decisions, and of the vital need for internal quarantine if site-led control is to be effective. Using both examples, we show how the likely impacts and the success and failure of eradication could be predicted from a knowledge of their biology gained through observation and experimental studies.

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AN INTERNATIONAL EXCHANGE OF BALLAST WATER RESEARCH BETWEEN NEW ZEALAND AND MASSACHUSETTS

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Key Words: New Zealand, ballast water, mid ocean exchange, effectiveness, compliance

Research on the ballast water problem in New Zealand since 1995 is briefly described, including the results of a two-year sampling survey of container ships and bulk carriers in the ports of Lyttelton and Nelson. Current research funded by the New Zealand Ministry of Fisheries, jointly involving both the Cawthron Institute in NZ and Battelle in Massachusetts, is looking at methods of measuring the water volumes exchanged by ships in mid-ocean (by reballasting and by dilution) and the efficiency of these exchanges in ridding tanks of unwanted species. The research also includes existing and potential methods that may be used by quarantine agencies to confirm independently that mid ocean exchanges have occurred. Other research by Cawthron, and funded by the Foundation for Research Science and Technology, which investigates the survivorship of species in ballast tanks, particularly on trans-Tasman Sea voyages, is also described.

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QUANTIFIED BALLAST WATER RISK ASSESSMENT: THE AUSTRALIAN APPROACH

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This paper details the ballast water risk assessment currently being developed by the Centre for Research on Introduced Marine Pests (CRIMP). The risk assessment comprises a series of modules that deal with discrete elements of the introduction cycle (port infection status, vessel infection scenarios, journey survival) up to and including survival in the recipient port environment. Several levels of assessment are catered for within each of the modules, allowing a progressively more accurate assessment with additional data. The risk assessment is species specific and in the first instance will be applied to a target list of marine pests. An assessment based on surrogate taxa, however, may allow an assessment of the wider introduction risk associated with ballast water and sediment discharges. The paper will address the role played by the risk assessment within the Decision Support System being developed by the Australian Quarantine and Inspection Service (AQIS), and will demonstrates its approach and results with reference to the further spread of Asterias amurensis from ports in SE Australia.

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EVALUATIONS OF MARINE ENCRUSTING COMMUNITY INVASIBILITY

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Key Words: encrusting community, fouling, invasibility, resistance

The Eltonian concept of a native community-level resistance to the invasion of new species forms the foundations of modern invasion theory. This paradigm has received tacit support from mathematical models and recent work in terrestrial plant communities supports the corollary argument that disturbance surmounts the intrinsic native resistance. An empirical evaluation of invasibility in a marine encrusting community of Coos Bay, Oregon is presented in which a reciprocal community transplant was used to explicitly test these assumptions. Species-rich (marine derived) communities were hypothesised to be less invasible (i.e., more resistant) than species-depauperate (estuarine) communities. In summary, native communities were susceptible to invasion in all instances, but to varying degrees. These differences in invasibility were primarily due to differences in native species cover at the outset of the experiment. These results are then compared with more recent information collected from a series of port surveys from around Australia.

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HISTORICAL AND MODERN INVASIONS TO PORT PHILLIP BAY, AUSTRALIA: THE MOST INVADED SOUTHERN EMBAYMENT?

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Key Words: survey, mechanisms, vectors, invasion rates

Port Phillip Bay (PPB) is a large (1900 km²), temperate embayment in southern Victoria, Australia. Extensive bay-wide surveys of PPB have occurred between 1803 and 1963. In 1995/96 the CSIRO Centre for Research on Introduced Marine Pests (CRIMP) undertook an intensive evaluation of the region with the aims of developing a comprehensive species list of native and introduced fauna and contrasting previous bay-wide assessments with a current field survey in order to detect new incursions and discern alterations to native communities. Two methods were used to meet these aims: a re-evaluation of regional museum collections and published research in PPB to identify and determine the timing of introductions; and field surveys for introduced benthic (infauna, epifauna and encrusting) organisms conducted by CRIMP between September 1995 to March 1996. The historic component of PPB invasions groups into four periods based on the record of first collection: exploration/colonisation; immigration; Gold Rush (1852-1860); and modern mechanisms (including aquaculture). Invasions within PPB appear to be increasing, possibly due an increase in modern shipping traffic and an increase in aquaculture (historically associated with incidental introductions). As expected, the majority of introductions are concentrated around the shipping ports of Geelong and Melbourne. Recent incursions into the region include Undaria pinnatifida, Codium fragile tomentosoides, Asterias amurensis, Schizoporella unicornis and Pyromaia tuberculata. Port Phillip Bay is presented as one of the most invaded marine ecosystems in the southern hemisphere.

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NONINDIGENOUS SPECIES IN HIGH LATITUDE/COLD WATER ECOSYSTEMS: PRINCE WILLIAM SOUND, ALASKA

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Key Words: ballast water, Alaska, plankton, transfer patterns, tankers

Although most studies of introduced species in marine ecosystems are for temperate latitudes, limited published research indicates invasions may also be common at high latitude. We are assessing the risk of biological invasions for Prince William Sound, Alaska, where tankers deliver large quantities of ballast water when loading crude oil from the trans-Alaska pipeline in Port Valdez. The study provides the first detailed analysis of the biological characteristics of tanker ballast water. Abundant and diverse plankton is being released in segregated (non-oily) ballast from source ports along the US west coast and some Asian ports. Plankton in ballast water varies significantly among years, seasons, and source ports. Temperature and salinity of ballast water is often similar to receiving water; and short-term tolerances of ballast water plankton overlaps the receiving conditions. Sediment in ballast tanks sometimes also contains abundant macro-invertebrates. Bottom fouling of tankers is usually minimal, but sometimes develops rich communities. Field surveys, fouling plate studies, and literature search identified several nonindigenous species already present in Alaskan waters. However, the Alaskan biota is characterized by many cryptogenic species, and few previous studies have focused on invasive species. On-going research is supported by a highly cooperative consortium of industry, government agencies, academic institutions, and private citizens.

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BIRD USE OF PHRAGMITES AUSTRALIS IN COASTAL MARSHES OF NORTHERN MASSACHUSETTS

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One of the major management concerns regarding salt marshes on the east coast is the replacement of existing salt and brackish vegetation by Common Reed, (Phragmites australis). This invasive grass thrives in areas where tidal flushing has been reduced by dikes, embankments, and undersized culverts. Phragmites habitats are thought to be of substantially less wildlife value than the marsh vegetation they replace. There is, however, little documentation of this assertion. With support from the Oak Knoll Foundation, we have carried out three seasons of quantitative bird censuses in Phragmites, Spartina, and coastal Typha marshes in northern Massachusetts. Census methodologies have included visual observation, passive listening and playback techniques in 50-meter radius point count circles. All birds seen or heard were recorded. Circles were selected that had various amounts of woods, Phragmites, Spartina, or Typha within them. Where the vegetation was tall, censuses were carried out from a 6-10 foot step ladder. The number of bird species commonly encountered in each habitat appears to differ, with Spartina and Phragmites marshes having the most and coastal Typha marshes the least number of species. Preliminary analysis of data on redwings, marsh wrens, Virginia rails, and salt marsh sharp-tailed sparrows indicates that the amount of Phragmites present within each point count circle has little impact on the numbers of these birds seen there. If the amounts of Typha and Phragmites within the point count circles are combined, a measure of the importance of tall structured marshes can be calculated. Marsh wrens are strongly impacted by increases in the amount of either salt marsh or woods present. No preference has been detected between Phragmites, and Typha, but they clearly seem to prefer either to salt marsh or woods. Redwings exhibited no such preferences, and appear to be about equally abundant in all plant communities sampled. Virginia rails did not exhibit a strong preference for Phragmites or Typha marshes over salt marsh habitats. Rather a moderate negative impact of Phragmites and a weaker positive impact of Typha was detected. This may, however, reflect the inadequacy of limiting comparisons of the abundance of plant communities to the point count circles alone. We plan to investigate the impact of differences in the amount of Phragmites outside of the sampling area as well. Finally, it is clear that variables other than the plant communities present have a major role in determining the distributions of most bird species encountered. Understanding what these factors are may have a major impact on how Phragmites is managed in the coastal environment.

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AN INVESTIGATION OF TECHNIQUES FOR VERIFYING AT SEA EXCHANGE OF BALLAST WATER

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In November 1997, the International Maritime Organization (IMO) developed Resolution A. 868(20), Guidelines for the Control and Management of Shipsí Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens. The resolution includes guidelines for ballast water management procedures for ships and port states and calls for other research to be conducted to minimize the risk associated with ballast water transfers. In an effort to reduce the risk to the waters of the United States, the U.S. Congress in 1990 enacted the Nonindigenous Aquatic Species Prevention and Control Act (NASPCA). In 1996, The National Invasive Species Act (NISA) was passed to expand the control of ballast water regulations to all vessels with ballast tanks. The law directs the Secretary of Transportation to develop guidelines to prevent the introduction and spread of nonindigenous species into U.S. waters via the ballast waters of commercial vessels. These guidelines, when developed, will apply to vessels that operate outside the exclusive economic zone and enter U.S. waters. The guidelines direct these vessels to undertake a ballast water exchange on the high seas if possible.

To comply with NISA, the USCG in April 1998 proposed voluntary guidelines to help control the invasion of nonindigenous species (US Federal Register, 1998). The proposed guidelines include voluntary ballast exchange for foreign ships entering all U.S. ports and making ballast water exchange reporting mandatory. The proposed guidelines provide a three-year window for voluntary compliance by ships entering all US waters after which the level of voluntary compliance will be assessed, and if compliance is insufficient, ballast water exchange may become mandatory in the U.S. and carry heavy penalties for noncompliance. One challenge facing the U.S. and other national regulators and enforcement agencies is how to verify whether ships are complying with mid-ocean exchange requests.

This paper describes an evaluation of potential measurements that could be used to develop accurate and defensible measurement technologies for verifying at-sea exchanges. A substantial set of parameters and techniques that could potentially be used to verify open ocean ballast water exchange were identified and evaluated. While no simple readily available technique was found, measurement of the optical properties of sea water using fiber optic techniques was identified as a method that could likely meet the goals of an easy to use, portable field unit, with high potential for discriminating water types.

A preliminary feasibility study was conducted to further assess the potential of this technique. Coastal samples collected from the major estuaries of the east coast of the United states, a set of coastal and harbor samples from New Zealand, plus samples from the Gulf Stream east of Miami, Florida and the Mediterranean sea off the coast of northern Sardinia, Italy were analyzed using high resolution excitation emission fluorescence techniques to develop 3-D Excitation Emission Spectra. The spectral data developed in the study were subjected to advanced statistical analysis to identify differences among the samples. These techniques demonstrated that the methodology could clearly measure differences among the various samples and indicated that the technique would likely provide the ability to discriminate between coastal and open ocean waters.

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WHY BALLAST WATER DISCHARGES SHOULD BE REGULATED UNDER THE CLEAN WATER ACT

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Key Words: ballast water, clean water act, management

I. The Plain Language of the Clean Water Act Requires NPDES Permits for Ballast Water Discharges

The Clean Water Act (CWA) prohibits "the discharge of any pollutant by any person" except as in compliance with specified sections of the Act, including the permitting provisions of § 402. 33 U.S.C. § 1311(a). The phrase "discharge of a pollutant" is defined to include "any addition of any pollutant to the navigable waters from any point source." 33 U.S.C. § 1362(12). Vessels are specifically defined as point sources in the CWA. 33 U.S.C. § 1362(14). Moreover, the CWA specifically includes "biological materials" in its definition of pollutants. 33 U.S.C. § 1362(6). The discharge of ballast water from vessels is a discharge of pollutants because ballast water is known to contain invasive plant and animal species as well as bacteria and viruses associated with human sewage. All of these pollutants qualify as "biological materials" within the meaning of the CWA. Additionally, ballast water is likely to contain other pollutants, such as oil, chipped paint, sediment, and toxins contained in ballast sediment.

Under the CWA, vessels qualify as point sources. Accordingly, when they discharge pollutants, they are required to have National Pollutant Discharge Elimination System (NPDES) permits. Although EPA has purported to exempt "discharge[s] incidental to the normal operation of a vessel" from the requirement to obtain a permit, 40 C.F.R. § 122.3(a), nothing in the CWA gives EPA the power to create categorical exemptions. Natural Resources Defense Council v. Costle, 568 F.2d 1369, 1377 (1977) (Costle). While EPA is given substantial deference in interpreting the CWA, it cannot rely upon regulations that are clearly contrary to the express statutory requirements. Chevron v. Natural Resources Defense Council, 467 U.S. 837 (1984), City of Chicago v. Environmental Defense Fund, 114 S.Ct. 1588 (1994).

The CWA does contain certain limited exemptions relating to the need to obtain NPDES permits for ballast water and other discharges incidental to the normal operation of vessels. None of these exemptions can reasonably be construed as permitting the blanket exemption contained in 40 C.F.R. § 122.3(a). First, the CWA excludes incidental discharges from vessels made in the "contiguous zone" and the "ocean" from having to obtain an NPDES permit. 33 U.S.C. § 1362(12)(B). These terms have clear statutory definitions: the "contiguous zone" begins three miles from shore and extends seaward to twelve miles from shore; and the "ocean," is any portion of the high seas beyond the contiguous zone. 33 U.S.C. § 1362(9) and (10). Thus, the effect of this exemption is that incidental discharges (such as ballast water) made outside of three miles from shore are not required to have NPDES permits. It cannot, however, reasonably be construed as applying inside the three mile contiguous zone boundary.

Second, the CWA specifically excludes two types of discharges from its definition of "pollutants." 33 U.S.C. § 1362(6)(A). The Act states that neither discharges of "sewage from vessels or a discharge incidental to the normal operation of a vessel of the Armed Forces," are to be considered pollutants. Id. (emphasis added). As a result of the second aspect of this exclusion, discharges incidental to the normal operation of Armed Services vessels are not required to have an NPDES permit. However, this exemption is specifically limited to Armed Services vessels; EPA cannot reasonably expand it to apply to all vessels, as it has done in 33 C.F.R. § 122.3(a).

It is important to note that, in exempting both sewage discharges and incidental discharges from Armed Services vessels, Congress specifically provided alternative programs for control of such discharges under other sections of the CWA. See 33 U.S.C. § 1322(b) (addressing sewage discharges) and (n) (addressing incidental discharges from Armed Forces vessels). The fact that there is no similar statutory or regulatory provision which addresses incidental discharges from non-Armed Services vessels under the CWA further highlights the Congressional intent that ballast water discharges be regulated under § 402 of the CWA .

The Act is clear that ballast water releases that contain biological materials qualify as point source discharges of a pollutant and that such discharges require NPDES permits under § 402. 40 C.F.R. § 122.3(a) runs directly counter to this plain statutory requirement and should therefore be repealed.

II. Existing Case Law Unequivocally Indicates that EPA Does Not Have the Discretion to Exempt Incidental Discharges from the Requirements of the CWA.

In Costle, the D.C. Circuit addressed the question of whether EPA could exempt agricultural return flows from the requirements of the CWA. 568 F.2d 1369 (D.C. Cir. 1977). The court unambiguously stated that the EPA did not have the authority to exempt discharges from the requirements of § 402. Finding that § 402 permits were central to achieving the stated goals of the CWA, the court found that "[t]he wording of the statute, legislative history, and precedents are clear: the EPA Administrator does not have authority to exempt categories of point sources from the permit requirements of §402." Id. at 1377; see also NRDC v. U.S. E.P.A., 966 F.2d 1292, 1305 (9th Cir. 1992); Carr v. Alta Verde Industries Inc., 931 F.2d 1055,1060 (5th Cir. 1991); Sierra Club v Abston; 620 F.2d 41, 44 (5th Cir. 1980); and U.S. v. Earth Sciences, Inc., 599 F.2d 368, 372 (10th Cir. 1979).

In reaching its result, the Costle court relied on both the language of the statute itself and its underlying legislative history. As noted by the court, the House Report addressed the effect of § 301 in the following terms:

Any discharge of a pollutant without a permit issued by the Administrator under section 318, or by the Administrator or State under 402 or by the Secretary of the Army under 404 is unlawful.

568 F.2d at 1374, citing H.Rep.No.92-911, 92d Cong., 2d Sess. 100 (1972), reprinted in Legislative History at 787. The court further noted that there were:

innumerable [other] references in the legislative history in the legislative history to the effect that the Act is founded on the "basic premise that a discharge of pollutants without a permit is

unlawful and that discharges not in compliance with the limitations and conditions for a permit are unlawful."

Id. at 1375.

In promulgating 40 C.F.R. § 122.3(a), EPA acted in direct violation of the straightforward rule established in NRDC v. Costle. EPA has created a categorical exclusion in a statutory scheme that permits of none.

III. Benefits of Clean Water Act Regulation.

Control under the CWA would have two components. First, EPA would be required to develop technology-based controls based on the "best available technology that is economically achievable" (BAT). Before EPA were to set this standard, the permit issuers (typically the states under the CWA) would be required to exercise their "best professional judgment" in trying to anticipate what the BAT standard would be when it were to come out. Thus, all ballast water dischargers would immediately become subject to technology-based controls.

As importantly, the permit issuers would be required to ensure--on a case-by-case basis--that the relevant dischargers would comply with water quality standards. Given that few (if any) states have water quality standards that directly address the issue of invasive species, the key short-term issue here would be compliance with the antidegradation policy. Under this policy, no discharge can be permitted if it will impair any "existing use" of the relevant waterbody. 40 C.F.R. § 131.12. Existing uses are defined to include any species that have inhabited a particular waterbody since November 28, 1975. 40 C.F.R. § 131.3(e). Thus, under the antidegradation policy, the permit issuer would be required to perform an analysis--as a precondition to permitting a discharge of ballast water to occur--that would be designed to preclude the possibility that any invasive species present in the ballast water might outcompete any existing (i.e., native) species.

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INSIGHTS FROM A TOY OCEAN: INVASION DYNAMICS IN LAKE VICTORIA AND IMPLICATIONS FOR MARINE COASTAL WATERS

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Key Words: Fishes, species interactions, water quality, Lake Victoria

A series of deliberate and accidental introductions into the worldís largest tropical lake can shed light on the dynamics of invasive species in semi-enclosed and isolated marine water bodies. We have examined the landscape dynamics and conservation genetics of the interaction between a rich indigenous fish fauna and three highly disruptive invaders in the context of chronic, progressive eutrophication in Lake Victoria, East Africa. The invading species are Nile perch (Lates cf. niloticus), Nile tilapia (Oreochromis niloticus) and water hyacinth (Eichornia crassipes). Following a series of rapid and catastrophic initial impacts including a mass extinction, a still-rich remnant indigenous fauna has exhibited an astonishing tenacity and resiliency. This is attributable mostly to the spatial and temporal complexity of refugia, the powerful shaping influence of water column conditions, and counterintuitive interactions between invaders and their indigenous relatives. Maintenance of indigenous taxa is partly dependent upon the amelioration of chronic water quality insults unrelated to the invasions themselves. Analogies are drawn to impacted and invaded coral reef systems.

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INTRODUCTION OF THE GREEN PORCELAIN CRAB, PETROLISTHES ARMATUS (GIBBES, 1850) INTO THE SOUTH ATLANTIC BIGHT

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Key Words: Petrolisthes armatus, oyster reefs, rocky shores, South Atlantic Bight

The green porcelain crab, Petrolisthes armatus (Gibbes, 1850), has a widely reported distribution in tropical western Africa and in the eastern Pacific from the Gulf of California to Peru. In the western Atlantic, it is found in Bermuda, the Gulf of Mexico, Caribbean, and south to Brazil. The species was collected from the Florida Atlantic coast at Biscayne Bay and Miami Beach as early as the 1930s, but it was still rare in the Indian River area as late as 1977. Although it has become well established in the Indian River system since that time, it was not reported north of Cape Canaveral, Florida until 1994. Faunal surveys at St. Catherines Island, GA did not reveal the presence of P. armatus prior to the fall of 1994, after which time it underwent a dramatic increase in abundance, becoming the dominant decapod crustacean on rocky substrates and tidal creek oyster bars by the following spring. In South Carolina, it was first observed in low densities in the spring of 1995 at various locations, becoming quite abundant by the fall of that year. It is now well established on rocky rubble, oyster reefs and other shallow subtidal and intertidal habitats throughout Georgia and South Carolina. The most northern collection to date is Winyah Bay, SC. Qualitative and quantitative data on abundance, geographic distribution, length-frequency, sex ratio, and reproductive status are presented to document the introduction of this species into the South Atlantic Bight. There are several possible pathways for the introduction of P. armatus into the SAB, both natural and anthropogenically assisted. Although we have no data to suggest which of these are the principal means of its establishment in this region, a number of those possibilities are presented. Studies are planned to examine the recruitment of this species and co-occurring decapods and to evaluate interactions between them.

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OCCURRENCE OF NONINDIGENOUS SPECIES IN THE GULF OF MEXICO

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Key Words: Gulf of Mexico, nonindigenous species, ballast water

The Gulf of Mexico is considered a large marine ecosystem (LME) because of its hydrography, geomorphology and the inter-relationship of its flora and fauna. It contains two zoogeographic provinces along with tropical, subtropical and temperate flora and fauna shared between three countries. A series of NOAA-EPA co-sponsored workshops on the introduction of nonindigenous species (NIS) in the Gulf of Mexico was held from June 1997 - September 1998. The workshops characterized the extent of NIS introduction phylogenetically and geographically, an overview of bioinvasion pathways, and a discussion of preventive recommendations and subsequent actions to be taken.

This phylogentic and geographical overview will address the introduction of primary shrimp viruses, zebra and brown mussels, coastal fishes, nutria and introduced flora. Pathways and unintentional distributions of species will be discussed with emphasis on the extent of shipping and potential ballast water exchanges in major Gulf of Mexico ports.

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PANEL DISCUSSION: COMMENT ON THE PREMISE

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The fact that "bioinvaders are here to stay" provides a strong motivation to prevent new introductions, in part because it infers an inability to address the problem once it arrives. However, despite our best efforts to eliminate the vectors of marine alien introductions, we will not be able to prevent all introductions. We will receive the burden of those that will come in addition to the very substantial economic and ecological burden of those that are already here. Prevention of further introductions will always be the most desirable option. But, prevention cannot supplant our duty to mitigate pests that are already here or who are yet to come. Further, if eradication of pests is the only meaningful outcome of a mitigation program, then we are doomed to fail.

Faced with the permanent reality of past invasions and the likelihood of future arrivals, some, perhaps out of fear or pessimism about the potential to control invaders, have embraced fatalism and say, "we will just have to learn to live with them." In many cases, this is wholly appropriate considering that only a proportion of introductions will have measurable ecological and economic impacts. However, when this fatalism extends to those species that are truly serious pests, it is an attitude that seems unique to the marine environment. For no other type of pest does our society generally first respond with "we can learn to live with it." Not for rabbits in Australia, the silverleaf whitefly in California, malaria nor AIDS. And when we do abandon control efforts, the cost can be awesome (e. g., fire ants in the southeastern USA). There is danger in the hypocrisy of this perspective because if there really are no marine pests that merit attempts at control programs, then why should the shipping industry and others be asked to bear such great costs in the prevention of introduction and spread of such pests? Let us instead move on to other problems such as trawling, over-fishing and pollution.

The conceptual salvation for this quandry is that not all introductions are pests and that the control of pests does not require eradication. If we can substantially reduce pest densities then we will greatly alleviate their impact. With this in mind, the great potential for economic and ecological impacts due to the high abundance of some existing introduced marine pests (e.g., mitten crab, Caulerpa, green crab, north Pacific starfish, shell-modifying sabellid) warrants considering a control strategy.

A proactive effort to control introduced marine pests requires an Integrated Pest Management (IPM) approach. This starts with a coherent general strategy and applies the principles from related and much more advanced pest control programs. Notably these are for agricultural insect pests, weeds, infectious agents and their vectors. These have all converged on some very basic principles of IPM:

1. Early detection of the introduced pest.
2. Rapid evaluation of the risk of their establishment and spread.
3. A generous evaluation of their potential impact and of the cost of no action.
4. Prompt detection of their natural enemies and other limiting factors where the pest is native.

This perspective generally calls for an aggressive and sometimes relatively expensive attempt to eradicate the newly established pest, and a longer term control plan including chemical and biological controls and other environmental manipulations. Biological controls are often the focus of these IPM strategies because of their proven environmental safety.

Ironically, some argue against the concept of biological control under the view that all introductions must be resisted with equal force because all introductions remove us from our goal of a pristine environment. This sort of romantic naturalism is a fantasy in our modern world. "Pristine" is an anachronism. As Dan Janzen emphasized in his seminal essay on "gardenification" (1998. Science 279:1312.), "the question is not whether we must manage nature, but rather how we shall manage it." In this context, the introduction of a biological control makes sense if it has good potential to reduce pest abundance with little risk of otherwise impacting the ecosystem. With Janzen, I believe ecologists must step up to the plate and use appropriate science to help solve these problems instead of simply calling out that the sky is falling.

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CAN BIOLOGICAL CONTROL BE DEVELOPED AS A SAFE AND EFFECTIVE MITIGATION AGAINST ESTABLISHED INTRODUCED MARINE PESTS?

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Key Words: biological control, marine pests, safety

We now have a broad scientific consensus that introduced marine species sometimes become serious environmental pests, and that actions to reduce their transport, entry, and establishment are very necessary. After their establishment at a point of entry, we presently have neither practical tools to prevent their further spread, nor to significantly reduce their impact on native organisms. Recently, the use of natural enemies, as developed for the classical biological control of introduced weeds and agricultural insect pests, has been proposed to significantly reduce the impact of those established marine pests that have the potential to cause great economic and ecological damage. The key issues concerning such an approach are clearly its efficacy and safety. Many marine biologists see this as a fruitful avenue for investigation. The cost of inaction is considered great enough to assume some risk towards its resolution. Others, however, fear that this approach has the potential to cause more harm than benefit. They raise two general arguments. Potential natural enemies are seen as a coming plague. Reference points include cane toads, rabbit calicivirus and some predatory land snails. For some, the irreversible nature of a biocontrol agent argues against even its further investigation. Somewhat paradoxically, the other argument is that a biocontrol agent will not be effective because the pest is common where it is native. Thus, the natural enemy cannot effectively reduce its density where the pest has been introduced.

Analyses from the studies of the efficacy and safety of weed and insect pest biological control will be applied to its potential use against introduced marine pests. The campaign against the endemic coconut moth of Fiji will be examined as an exemplar of the scientific, cultural and economic values that may lead to conflict in the application of a biological control program for a pest.

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POTENTIAL IMPACT OF THE RECENTLY INTRODUCED ASIAN SHORE CRAB, HEMIGRAPSUS SANGUINEUS, ON ROCKY INTERTIDAL COMMUNITIES OF THE NORTHEASTERN U.S. COAST

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Key Words: Hemigrapsus sanguineus, crustacean, distribution, ecology, rocky intertidal, feeding rates

The Asian shore crab Hemigrapsus sanguineus was introduced to the mid-Atlantic coast in the late 1980ís. We have been studying population density and distribution on a cobble/boulder beach in central Long Island Sound. We have also done preliminary experiments on feeding activity. Average seasonal abundance on the cobble shore at Crane Neck Point during 1997-1998 ranged from 7-9 m-2. During the summer, the crabs were fairly evenly distributed at different elevations in the intertidal zone; however, they appeared to move from high to low elevation during the winter. The crabs readily consumed all common species of macroalgae and invertebrates occurring at Crane Neck Point. Based on laboratory experiments, we estimate that approximately 49-162 juvenile (<10mm) Littorina littorea and 28-171 small (<20mm) Mytillus galloprovincalias could be consumed daily per m2. Reduced foraging efficiency in the field where more cover is available for prey items, may result in actual predation rates that are considerably lower than these estimates. However, based on high crab densities and feeding rates on the early stages of these keystone species, we predict that this recent invader will strongly impact the community structure of the rocky intertidal in the western north Atlantic. Ironically, much of the impact may occur through predation on Littorina, a previously introduced species which itself has had a major impact on these communities.

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XENODIVERSITY OF THE EUROPEAN BRACKISH WATER SEAS: THE NORTH AMERICAN CONTRIBUTION

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Key Words: Baltic Sea, Black Sea, introduced species, macrobenthos

Fauna and flora of the worldís two largest brackish water bodies, the Baltic and Black Seas, have been changed during the recent centuries. Until now, more than 100 of known or thought to be non-native species have been included in a Baltic and Black Sea Alien Species Database created by the Baltic Marine Biologistsí expert group (http://www.ku.lt/nemo/mainnemo.htm). We define this "foreign" biological diversity as xenodiversity in order to indicate the diversity caused by non-native species both at species and functional groups/life forms levels.

Out of the 52 unintentional introductions into the Baltic Sea with more or less known dispersal history, 32 are transoceanic; among them there are 15 trans-Atlantic ones of American origin. Typically the Atlantic coast of North America has exported more marine species to Europe than the other donor areas. This successfulness might be related more to the successive opening of routes of commerce in the post-Columbian and post-Cookian era than to the competitive vigor of the invaders from America. Once established, the most successful non-native, invasive species have spread rapidly, among them some Neo-Europeans of American origin. The soft-shell clam, Mya arenaria, is thought to be transported by the Vikings in the 13th century, the barnacle Balanus improvisus appeared in the late 1800's, and the polychaete, Marenzelleria viridis, in the 1990's.

The recent deterioration history of the Black Sea ecosystem offers a dramatic example of an ecological catastrophe caused by alien species. Within ten years (since 1982), a decrease of anchovy catch took place simultaneously with the expansion of the American comb jelly, Mnemiopsis leidyi.

The European history of non-native aquatic species can be divided in three eras: 1) early accidental introductions; 2) period of experimenting with economically beneficial species; 3) modern time introductions, with intentional ones more or less banned, but unintentional increasing, mainly due to ballast travelers. The role of non-native species in ecosystem functions and their ability to displace native species in the Baltic Sea is still badly understood. Especially in coastal inlets and lagoons, they tend to markedly alter the habitats they invaded or were introduced to. They increase the 3-dimensionality of the benthic habitats, broaden the food base of bottom and plankton eating fish, link benthic and pelagic subsystems, and create new microhabitas for associated fauna.

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PATTERNS AND PREDICTABILITY OF BIOLOGICAL INVASIONS: A THEORETICAL FRAMEWORK AND A CASE STUDY USING THE WESTERN PACIFIC SHORE CRAB HEMIGRAPSUS SANGUINEUS

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Key Words: Hemigrapsus sanguineus, crabs, niche theory, framework, prediction

One of the primary questions at the heart of invasion ecology is why some exotic organisms can succeed in "fitting" into communities with which they have no shared evolutionary history while resident community members fail to evade those same exotic organisms. Ecological niche theory, specifically the theory of limiting similarity, provides an excellent framework for addressing this question. Patterns among successfully invasive organisms (e.g., life history characteristics; trophic position) or among the ecological communities they invade (e.g., community diversity/richness; level of habitat disturbance) have been difficult for invasion ecologists to fully elucidate. Presented here are theoretical models of invasion, based on niche theory, that provide a predictive context for research on new invasions. Further, we provide a case study applying this framework to the recently introduced Western Pacific shore crab, Hemigrapsus sanguineus, using field data collected from its native (Japan) and invaded (southern New England) range. A systematic examination of other species introductions using this framework should clarify the most common patterns, thereby enabling better predictions of potential ecological and economic impacts of alien species.

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EFFECTIVENESS OF FUNCTIONAL FEEDING MODES OF INVASIVE AND NATIVE PREDATORS

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Key Words: feeding mode, prey selection, whelk

A novel function may provide an invasive species with advantages relative to natives. In particular, invasive predators might have an advantage if they introduce a novel functional feeding mode to native prey. Models of coevolution can both support and refute this assertion. A lack of coevolution may provide invasive predators with an advantage, because native prey have ineffective or inappropriate anti-predatory defenses. Conversely, invasive predators may be outcompeted by native predators for native prey. The recent expansion of Kellet's whelk, Kelletia kelletii, from south of Point Conception northwards to Monterey Bay, California introduced a novel feeding mode to the guild of invertebrate predators preying on trochid snails in central California. Before the appearance of Kelletia in 1980, sea stars (an ecological equivalent of whelks) were the primary invertebrate predators of trochids in central California. Stars feed using an eversible stomach while Kelletia feeds with a prehensile proboscis.

I used native and non-native sea stars and whelks as predators and allopatric Tegula spp. as prey in a series of non-choice and choice experiments to: 1) compare consumption rates between different functional feeding modes; and 2) assess prey anti-predatory defenses within the genus Tegula. I used the southern rainbow star, Astrometis sertulifera, which feeds on trochids but occurs only in southern California to represent a non-coevolved predator in central California, and the giant spined star, Pisaster giganteus, which occurs in both southern and central California to represent a coevolved predator. Three subtidal macroherbivores in the genus Tegula were used as prey, one from central California (T. brunnea) and two from southern California (T. aureotincta, T. eiseni). In a non-choice experiment, I compared T. brunnea and T. aureotincta, both of which are poorly defended relative to sympatric congeners. Consumption rates were always highest for T. aureotincta. In a second non-choice experiment, I compared T. eiseni, which is well-defended, to T. brunnea. Astrometis consumed both prey species at equal rates, while both Pisaster and Kelletia ate significantly more T. brunnea than T. eiseni. Deep withdrawal by T. brunnea was a partially effective defense against sea stars, but it was less effective against the novel feeding mode of Kelletia. Escape frequency and consumption time were greater for T. eiseni. Among predators, Kelletia ate a significantly higher proportion of T. brunnea than either Pisaster or Astrometis. In a binary choice experiment using only southern California prey, all predators consumed T. aureotincta almost exclusively. Combining these results, T. aureotincta was most preferred, followed by T. brunnea, and T. eiseni was consumed when other prey were unavailable. The high performance of the whelk relative to the native and non-native sea stars indicates that its novel functional feeding mode is advantageous.

For Pisaster and Kelletia, performance was not influenced by geographic origin; individuals from populations separated by 500 km consumed prey at nearly identical rates. This similarity between widely separated populations does not fit models of coevolution that predict local adaptation and thus differences between populations. Predator performance was enhanced by novelty of function, and not by novelty as a species.

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RAPANA VENOSA IN THE CHESAPEAKE BAY: CURRENT STATUS AND PROSPECTS FOR RANGE EXTENSION BASED ON SALINITY TOLERANCE OF EARLY LIFE HISTORY STAGES

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Key Words: Rapana venosa, gastropod, Chesapeake Bay, larvae, salinity tolerance, range

The Veined Rapa Whelk, Rapana venosa, has recently been identified as present in the Hampton Roads region of the Chesapeake Bay. The species is native to the Sea of Japan, but was introduced to the Black Sea in the 1940ís, and has since spread to the Aegean and Adriatic Seas. There is strong evidence that range extension is mediated by transport of early life history stages in ballast water. The current status of knowledge of distribution of R. venosa in the Chesapeake Bay is described. There is concern over the potential impact of Rapana venosa on local shellfish populations and the industry that they support. Egg cases of R. venosa have been collected from the field, and larval forms cultured in the laboratory. Estimates of the salinity tolerance of the larval stages of Rapana venosa are described as a precursor to estimating a potential range of distribution of the species within the Chesapeake Bay and its subestuaries. Such estimates are crucial to establishing which shellfish resources are potentially susceptible to predation by local Rapana venosa populations.

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PULSE GENERATOR FOR BIOFOULING PREVENTION

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Zebra mussels are a vigorous mollusk thought to originate in the Black Sea. Given a foothold the zebra mussels will colonize the area, killing off native species, and populate structures and pipes which can reduce water flow in critical cooling and irrigation operations tounsatisfactory levels.

The literature suggests that pulse power can be an effective and potentially economic method as a primary or as a complement to a mix of chemical and/or mechanical prevention/control technologies currently in use. The pulsed power method stuns or kills the veligers in the pipe entrance and has no effect on animals upstream of the entrance, nor downstream from the system discharge.

An experimental 20Kv pulse will be described which has been used to suppress zebra mussel settlement by more than 80% in a power plant cooled by Mississippi River water. Methods for improving the effectiveness and cost will be described. Finally, application of this technique to control other marine species will be touched upon.

THE USE OF MOLECULAR GENETICS TO INVESTIGATE THE GEOGRAPHIC ORIGIN AND VECTOR OF AN INVASIVE SPECIES

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Key Words: molecular genetics, ballast water, origins of invasive species

Knowledge of the geographic origin of an invasive species can contribute to the identification of the vector responsible for its introduction. Although it is often difficult to determine the origin of introduced species, the use of molecular genetics can help to identify possible sources. In 1996, a large red alga, Grateloupia doryphora, was recorded for the first time in Narragansett Bay, RI. Since its arrival, it has continued to spread and will likely have an effect on native biota. In an effort to identify the geographic origin and vector, we have obtained G. doryphora individuals from locations around the world. Genetic analyses of these individuals (using ITS sequences and RAPDs) suggest that this introduction is not due to marginal dispersal. Based on the pattern of ship traffic in Narragansett Bay and the locations of the first G. doryphora populations, it seems likely that either hulls of ships or ballast water-dumping were involved in the introduction, and our genetic data provide further evidence for this mode of introduction.

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SYSTEMS FOR EVALUATION OF SHIP-BOARD BALLAST WATER TREATMENT TECHNOLOGIES FOR PREVENTING TRANSFER OF UNWANTED ORGANISMS

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Key Words: Ballast water, treatment, management, disinfection, filtration, biocides, pilot scale studies, dinoflagellate

The environmental damages caused by transfer of unwanted organisms in ballast water are well understood and research efforts are needed for treatment and control. The Environmental Technology Institute (ETI), Singapore in collaboration with The Maritime Port Authority (MPA) and National University of Singapore (NUS) has initiated a multi-faced research and development project on ballast water including a pilot scale evaluation of possible ship-board treatment system to remove unwanted micro-organisms. The first phase of this project consists of a 250 gpm pilot plant, incorporating innovative self-cleaning strainers and multimedia pressure filtration systems. Inactivation studies of surrogate microorganisms using biocides have been initiated in parallel laboratory scale experiments. These studies are complemented with the development of a reliable bio-monitoring technique to determine the biocide ($C \cdot t$) relationships using dinoflagellate cysts as indicator organisms. This paper discusses the status of this on-going research and preliminary findings.

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TRANSPORT OF MARINE ORGANISMS VIA SHIPSí BALLAST INTO PORTS AROUND ENGLAND AND WALES

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Key Words: Ballast water, non-native species, introduced species

A three year study to investigate the transport of marine organisms in shipsí ballast water is being carried out on behalf of the Ministry of Agriculture, Fisheries and Food by the School of Ocean Sciences, University of Wales, Bangor. The aim of the project is to determine the type and number of viable organisms transported in segregated ballast water and sediments from ships coming into England and Wales from foreign sources. The project is closely related to a research programme carried out by the Aberdeen Marine Laboratory for Scottish ports and the results from both projects will be collated in a common database. A number of ports in England and Wales have been visited to sample different types of vessels ranging in size from small coasters to large oil tankers. To date, 101 samples have been collected, with the origin of the majority of the ballast water being Northern Europe. The samples were taken using pumps, hoses and plankton nets, preferably via opened deck hatches but also from sounding pipes and overflowing air pipes. The water and net samples were examined for phytoplankton and zooplankton and the sediment for dinoflagellate cysts.

All but one of the water samples contained motile phytoplankton. Both fresh water and marine species were found. Diatoms were the most common group present. There was some evidence of a seasonal pattern reflecting temperate spring and autumn blooms. Cell numbers varied from just over 1,000 cells per litre to 5 x 106 cells per litre. Some toxic and/or nuisance species were found e.g. Pseudonitzschia multiseries, Dinophysis sp., Dictyocha sp, Ceratium sp., and Phaeocystis sp. Although these species are native to British ballast water these results demonstrate that ballast water is one vector by which nuisance species can be moved to areas where they may not have previously caused a problem.

Dinoflagellate cysts have been recorded in 80% of the sediment samples. A total of 22 species representing 11 genera have been identified, the cysts of Protoperidinium and Scrippsiella species being the most common. Scrippsiella hangoei and Gymnodinium catenatum, two species not previously recorded in British waters have been identified as have some potentially toxic species, of which Alexandrium tamarense/catanella was the most common.

Analysis of the zooplankton samples is underway and, as identification of the preserved samples is often difficult, live samples are also collected whenever possible in order to grow larvae to aid identification. For example, a megalopa larvae of the non-native species Cancer irroratus was reared in the laboratory under ambient conditions thus demonstrating the potential for this species to survive in British waters.

The findings of the project so far demonstrate that non-native species are being transported into English and Welsh ports. There is therefore a potential risk of non-native species subsequently becoming established within British waters. There is evidence that this has happened in the past with thirty of the fifty non-native species in British waters thought to have been introduced via shipping.

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A REVIEW OF THE NATURAL HISTORY OF THE ASIAN SHORE CRAB HEMIGRAPSUS SANGUINEUS IN THE WESTERN ATLANTIC WITH ADDITIONAL INFORMATION ON ITS BIOLOGY

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Key Words besides those in title: geographic range, grapsid crab, molting, New Jersey, reproduction, salinity tolerance

In the 1980's, the western Pacific grapsid crab, Hemigrapsus sanguineus, occupied an open niche in the middle to upper rocky intertidal along the mid-Atlantic coast of the United States. Several aspects of its biology and ecology in Atlantic waters have been elucidated previously, and these are briefly reviewed. Recent studies showed that the crab's northern geographical range extends to the coast of New Hampshire. Additional information on the length of its reproductive season in New Jersey verified that reproduction ends in September. Large numbers of molted exoskeletons of H. sanguineus and Carcinus maenas, found along a beach adjacent to a rocky habitat in New Jersey, were collected and measured. The size frequency distribution of Hemigrapsus molts showed similarities to the living population among the rocks. Carcinus molts were approximately equal in number to those of Hemigrapsus. Laboratory observations showed that adults of H. sanguineus survive salinity reductions down to 10 ppt.

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SOURCES FOR GLOBAL INVASIONS BY THE CRAB, CARCINUS MAENAS, USING SEQUENCE VARIATION IN THE MITOCHONDRIAL CYTOCHROME OXIDASE GENE

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Key Words: biological invasions, Carcinus maenas, phylogeography, mitochondrial DNA, population genetics

The European crab in the genus Carcinus has invaded five regions. Previous genetic analysis of the mitochondrial 16S ribosomal RNA gene in Carcinus allowed identification of Mediterranean or the Atlantic sources for introduced populations. However, more genetic variation partitioned geographically in Europe is needed to track sources for the invasions in a more refined way. We examined sequence data from mitochondrial cytochrome oxidase b (cyt-b) gene among introduced and native populations of Carcinus. A 450 bp portion of cyt-b was amplified using PCR for 125 individuals from various native populations and 237 individuals from introduced populations in Japan, Australia, South Africa, California and New England. Cyt-b sequences were much more variable than16S rRNA sequences, with 191 haplotypes in our sample. Sequences were aligned and geographic structure was inferred from genetic distances among populations. Despite high variability of cyt-b, identification of source regions was confounded by strong genetic bottlenecks associated with colonization events for most introduced populations.

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IMPLEMENTATION OF THE NATIONAL INVASIVE SPECIES ACT OF 1996 (NISA)

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Key Words: NISA, ballast water, regulations, Coast Guard, exotic species, nonindigenous species, aquatic nuisance species

In 1996 the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 was amended by the National Invasive Species Act of 1996 (NISA) to further address the spread of nonindigenous species. To implement NISA, the Coast Guard is developing regulations that will establish (1) a voluntary ballast water management program for all vessels entering U.S. waters from outside of the Exclusive Economic Zone (EEZ) and (2) require the reporting of ballast water management data by all vessels entering U.S. waters from outside of the EEZ. A notice of proposed rulemaking was published in April 1998 and the Coast Guard is working towards issuing a rule in Spring 1999. The Coast Guard, in cooperation with the Smithsonian Environmental Research Center, is developing a nationwide program to measure ballast water management and delivery patters for commercial vessels that arrive in U.S. ports from outside of our EEZ. This National Ballast Survey is designed explicitly to create a national database on ballast water practices. Coast Guard field personnel will be involved in the collection of data to verify the accuracy of data submitted under the new regulations.

The Coast Guard heads the U.S. delegation to the International Maritime Organization (IMO) Marine Environment Protection Committee where work is underway to draft a legally binding international ballast water management instrument. A key goal of the U.S. is that the instrument includes a flexible framework that will encourage the development of new, safer and more effective ballast water management technologies.

The presentation will provide status reports on the proposed domestic regulations, Coast Guard ballast water survey and enforcement efforts, and international negotiations at IMO.

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UNITED STATES COAST GUARD BALLAST WATER MANAGEMENT VIDEO "PREVENTING AND CONTROLLING THE SPREAD OF AQUATIC NUISANCE SPECIES"

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MEASURING BALLAST WATER EXCHANGE PATTERNS: THE NATIONAL BALLAST SURVEY (NABS)

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Key Words: National Ballast Survey, ballast water exchange, ballast water management

The National Invasive Species Act of 1996 (NISA) directed the United States Coast Guard and the Smithsonian Environmental Research Center (SERC) to create the National Ballast Water Information Clearinghouse. The Clearinghouse, located at SERC, plays a central role in the organization and analysis of national data concerning the transfer and invasion of nonindigenous species associated with ballast water of ships. The Clearinghouse and U.S. Coast Guard are now implementing a nationwide program, the National Ballast Survey (NABS), to measure patterns of ballast water management (exchange) and delivery for commercial vessels that arrive to U.S. ports from outside of the nationís Exclusive Economic Zone. NABS is designed explicitly to create a national database on ballast water to (1) measure ballast water attributes according to vessel class for geographic region and season of arrival, (2) measure among-year changes in ballast water management by vessel class and geographic region, and (3) assess accuracy of data through use of multiple, independent data sources. The National Ballast Survey will result in a comprehensive analysis and biennial report to the U.S. Congress on the status of ballast water management and delivery throughout the country. Although NABS will not include policy recommendations, this analysis will be used in evaluation of compliance with NISA guidelines for ballast water exchange and thereby contribute to future national policies on ballast water.

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THE 1998 PUGET SOUND EXPEDITION: A RAPID ASSESSMENT SURVEY FOR NONINDIGENOUS SPECIES IN THE SHALLOW WATERS OF PUGET SOUND

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Key Words: Rapid Assessment, Puget Sound, invertebrates, algae, Zostera, Spartina, Washington, San Francisco Bay

A Rapid Assessment survey of 23 primary stations and 8 secondary stations was conducted September 8-16,1998 in the inland marine waters of Washington State from Blaine to Olympia. The Expedition team was composed of scientists with both broad and specific taxonomic expertise from several universities and local agencies. It included core researchers from the four San Francisco Bay Expeditions of 1993-1997, when the techniques used were pioneered; findings from Puget Sound are compared with those from San Francisco Bay. Using a variety of sampling methods at dock-fouling stations and adjacent shallow water benthic habitats, the Puget Sound Expedition team collected and identified 38 nonindigenous species (3 plants and 35 invertebrates) -- further taxonomic work on the samples is ongoing. The number of nonindigenous species collected per site showed no obvious pattern with regard to salinity, temperature or oceanographic basin. Four prior lists of nonindigenous marine species in Puget Sound and adjacent waters have been produced. We have developed an updated and corrected list of 52 nonindigenous marine and brackish water species that appear to be present and established in Puget Sound. The comparable species list for San Francisco Bay numbers well over 200 species.

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UV DISINFECTION OF BALLAST WATERS: EFFECTS OF ORGANISM SIZE ON SYSTEM SCALING

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Key Words: ultraviolet light, UV, filtration, system scaling

Ballast water has been demonstrated to be the principal vector for unintentional introduction of non-native species (Carlton and Geller 1993). A number of treatment options, both physical and chemical, have been proposed and UV sterilization remains a viable and environmentally benign approach. Developments in UV technology using high powered sources in the germicidal region of the UV spectrum (developed to treat bacteria in metal working fluids) have enabled the efficient delivery of doses capable of inducing acute and latent phototoxicity in a wide variety of organisms. In this investigation we evaluate the efficacy of high intensity UV irradiation (at >100 of mwatt/cm2) in controlling planktonic organisms likely to be entrained in ballast water. These include larval and adult crustaceans, larval bivalve mollusks, larval fish and microalgae. Since this technology will likely be combined with some physical filtration for shipboard installations, the relationship between organism size and effective UV dose becomes an important consideration. Here, we present preliminary data on size/dose relationships obtained from an experimental flow cell. These data are used to generate a figure of merit for scaling full-scale UV treatment systems.

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DEVELOPMENT OF AN AQUATIC NUISANCE SPECIES BARRIER IN A COMMERCIAL WATERWAY

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Key Words: invasive, nuisance, exotic, barrier, control

The NISA Act of 1996 authorized the Corps of Engineers to carry out a demonstration study of an aquatic nuisance species dispersal barrier in the Chicago Sanitary and Ship Canal. This location is of great interest as the century old, man-made canal is the only aquatic link between the Mississippi River and Great Lakes drainages and forms a two-way avenue for invasive species dispersal. Today the canal is used by commercial navigation for transportation of freight via barges between Lake Michigan and the Illinois Waterway, which links with the Mississippi River and to carry wastewater away from Lake Michigan, Chicago's drinking water supply. Though frequented by recreational vessels, the canal is not used for water skiing or swimming.

To identify likely dispersal barrier methodologies the Chicago District Corps assembled a Dispersal Barrier Advisory Panel comprised of 26 federal, state, academic, regional, municipal, commercial and environmental member entities. Recognizing that 100 percent control was unrealistic, the Panel members agreed that the objective of the barrier should be to reduce, to the extent possible, the dispersal of invasive species. No migratory species traverse this man-made canal however the barrier is expected to affect the passage of native as well as invasive species. Due to the commercial uses of the canal and its importance to Chicago's drinking water, closure of the canal or installation of physical barriers were not considered practical.

Ownership and interests along the canal are complex and early and ongoing involvement of the Advisory Panel members has been key to the progress of the project thus far. For example, though the Corps maintains the canal, the Metropolitan Water Reclamation District of Greater Chicago, a municipal agency, owns it and the adjacent lands. The lands are leased to marine-based commercial users and the County Forest Preserve.

The project has three phases. Phase I will target bottom dwelling species, particularly the round goby (Neogobius melanostomus). Phase II will target actively swimming organisms in the entire water column. Finally, Phase III will address planktonic organisms.

Construction of Phase I, which will consist of an electric barrier array, is expected to begin in Spring 1999. Laboratory and small-scale field trials currently in progress will help identify ideal field intensities and potential effect on native species. Monitoring of the project will help determine its success and effectiveness. Development of Phase II is already underway; implementation of the full water column electric barrier depends in part, upon safety and liability concerns. Other methodologies under consideration or development include infrasound, bubble screens and water jets. Though considered effective, at this time, chemical control was recommended for use only as a stopgap or emergency measure.

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IMPORTATION OF ORGANISMS ASSOCIATED WITH BAIT WORMS FROM VIETNAM

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Key Words: bait, microorganisms, Vibrio

The importation of bait creates a potentially important pathway for invasions by nonindigenous species and their associated biota. Since at least 1994, a large nereid polychete worm has been imported from Vietnam and distributed to various places in California, Maryland, and Oregon for use as fishing bait. We measured the abundance of microorganisms, and especially Vibrio bacteria, associated with these bait worms and the material in which they were shipped. Twelve worms were obtained directly from various bait shops in the Maryland/Virginia area. Both the worms and packing materials were analyzed using a range of techniques. We measured the abundance of many taxa by direct counts under a compound microscope. We estimated the abundance of culturable Vibrio bacteria, using standard plating techniques on agar. We also measured the abundance of two serotypes of Vibrio cholerae, using monoclonal antibodies for direct detection. Our results indicate diatoms, ciliates, flagellates, nematodes, and at least seven different genera of amoebae were present in the packing materials. In addition, we found multiple species of Vibrio, including both serotypes of V. cholerae. Although the fate of these organisms upon release remains unknown, our data indicate an active pathway exists for invasion of many different microorganisms and possible pathogens.

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DISTRIBUTION AND ABUNDANCE OF CTENPHORES AND THEIR ZOOPLANKTON FOOD IN THE BLACK SEA. II. MNEMIOPSIS LEIDYI

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Key Words: Black Sea, Ctenophora, Mnemiopsis, distribution, biometry, stomach content

The distribution of Mnemiopsis leidyi, Agassiz 1865, in the Black Sea was determined using plankton samples collected above the anoxic zone (maximum depth 200 m) in the summer, winter, and spring from 1991-1995. Distribution was patchy. Average biomasses of 15 to 500 gm-2 were measured and abundances varied from 10 to 180 individuals m-2. Biomass and abundance peaked in winter and there was a secondary peak in the summer. The distribution of M. leidyi was correlated with hydrographic features in the Black Sea with higher concentrations in anticyclonic gyres. The centers of the two main cyclonic gyres generally had a low biomass of M. leidyi. From July 1992 to March 1995, the populations were largely offshore. M. leidyi were confined to the upper part of the mixed layer both day and night. Some individuals displayed a negative taxis to daylight and, localized below the thermocline at night. Smaller M. leidyi (1.5-2 cm) were present in the winter and individuals reached maximum size in the summer. Although reproduction was continuous throughout the year, there were two distinct peaks: the larger peak in the summer and the smaller peak in the winter. Microscopic analysis of stomach contents showed that copepods and molluscs form their main diet.

INFLUENCE OF VESSEL TRANSIT PATTERNS ON BALLAST WATER TREATMENT OPTIONS OR EXOTIC AQUATIC ORGANISMS

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Key Words: vessel transit, ballast water, exotic aquatic species

Ballast water discharge has been identified as an important means of introducing exotic aquatic organisms to waters well beyond their natural geographic range. Preventative measures such as offshore exchange have been used with some success by vessels carrying exchangeable ballast. Efforts to develop active treatment measures have so far not been successful because of a large number of variables. Major factors that can influence a treatment program include the target organisms which can range from microbes to fish, matrices that include water and sediment, volume of ballast treated, and its application based on onboard equipment or requiring an external source. The treatment itself may have a chemical, physical or mechanical basis. Vessel transit patterns can influence treatment methods, and time of application should be compatible with vessel operational procedures.

Vessel transit patterns will differ among ports because of traffic volumes and transit routes. This factor was examined by tabulating the frequency of visits by overseas and nonregional vessels to Canadian maritime ports at Halifax, Vancouver and Prince Rupert, and freshwater ports on the Great Lakes. There were about 420 vessels from overseas or distant ports of departures that visited the Port of Halifax between 1992 and 1997; 2400 vessels to the Port of Vancouver between 1995 and 1997; 1170 vessels to Port of Prince Rupert between 1992 and 1997; and 880 vessels to Great Lakes ports between 1989 and 1997. Tabulation on the basis of the number of visits indicated that 46 to 71% of the vessels visited a port once during the 3 to 9 year periods reviewed. Furthermore, 68 to 96% of the vessels averaged 2 or less visits per year over the same period. The relatively high level of single visits and low frequency of repeat visits to these ports could deter the adoption of possible regulations that would require the installation of onboard ballast water treatment equipment on vessels before port entry, unless this requirement is applied at the international level.

Voluntary or mandatory exchange is used by some ports as a preventative measure, but its effectiveness is limited to vessels carrying exchangeable ballast. Offshore ballast exchange could be effective at the Ports of Vancouver and Prince Rupert because over 90% of the total cargo handled is exported, therefore most of the inbound vessels arrive in ballast. In contrast, ballast water exchange may not be an effective preventative measure on the Great Lakes because about 50% of the total cargo handled is exported, and over 80% of the overseas vessels enter with no exchangeable ballast on board (NOBOB).

A vessel monitoring program may be required to assess the level of compliance of a ballast water treatment program. Annual visits by nonregional vessels averaged about 400, 1820, 310 and 470 for the Ports of Halifax, Vancouver, Prince Rupert and ports on the Great Lakes. The frequency of these visits may not be a limiting factor in their assessment because arrivals of 1 to 3 vessels per day were the most frequent at the Ports of Halifax and Prince Rupert, and ports on the Great Lakes, but could be a factor at the Port of Vancouver where 5 to 9 vessels arrive per day. Access to vessels arriving at the three maritime ports for inspection and possible treatment could be a problem. Access to vessels entering the Great Lakes is greatly

facilitated by the need for all vessels to pass through a series of seven locks between the city of Montreal and Lake Ontario.

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NORTHWARD EXTENSION OF THE GEOGRAPHIC RANGE OF HEMIGRAPSUS SANGUINEUS IN MASSACHUSETTS, 1996-1998

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Key Words: Hemigrapsus sanguineus, geographic distribution, crab, range extension

Hemigrapsus sanguineus, a crab (family Grapsidae) native to the western North Pacific Ocean, was established on the east coast of the United States by 1990. Its abundance noticeably increased between 1993 and 1994 in Buzzards Bay, Massachusetts. In 1996, we received reports of the crab in Sandwich and Wellfleet on Cape Cod, and on Martha's Vineyard. Since 1996, we have been tracking the northward spread of the species and monitoring changes in newly-established populations in Cape Cod Bay, Nantucket Sound, and Narragansett Bay. In 1996, density estimates were made on populations in Sandwich (Cape Cod Bay) and Washburn Island, part of Waquoit Bay National Estuarine Research Reserve (Nantucket Sound). In 1997, the population on Washburn Island had increased more than ten-fold. Hemigrapsus sanguineus was also present in 1997 in Manomet (Plymouth, MA) and near Brant Rock (Marshfield, MA), along the shore of Cape Cod Bay. By 1998, H. sanguineus was found as far north as Scituate, MA, and populations in Plymouth and Marshfield had doubled in size. In addition, well-established populations occurred on Hope Island, in the middle reaches of Narragansett Bay.

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BALLAST WATER TREATMENT: POTENTIAL SHIP-BOARD OPTIONS AND IDENTIFYING STRATEGIC RESEARCH NEEDS

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Key Words: ballast water treatment, treatment options, future research direction

A number of research groups have been working on ballast water treatment options, resulting in a considerable refining of the treatment options which can be applied to ballast water treatment. This paper summarises briefly the options which are presently appropriate for ship-board ballast water treatment, discusses the limitations of these options and presents a list of the options which can realistically be expected to work. Research required to develop these technologies are discussed. Methods which are recommended for further research include: further examining the efficiency of ballast exchange processes, filtration, UV irradiation, heat treatment and other biocidal approaches. Research methods include computer modelling, laboratory tests, pilot tests and field testing, depending on the current state of knowledge for each option.

An important aspect of ballast water treatment is the need to compare the costs of the treatment options. For this to be done effectively standards need to be developed for ballast water treatment. At present there are two incompatible de facto standards based on the efficiency of ballast water exchange and on the inactivation of hypnocysts of some species of dinoflagellate algae. To accurately compare treatment options requires biological research which begins to identify the effectiveness that is required to stop a number of organisms from surviving all stages of the ballast water transport cycle. As this understanding begins to develop, the treatment options can be compared on the basis of the cost required to meet set standards of discharge for a range of organisms.

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THE NATIONAL AQUATIC NUISANCE SPECIES CLEARINGHOUSE SEARCHABLE ELECTRONIC DATABASE: A TOOL FOR RESEARCHERS WORLDWIDE

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Key Words: aquatic nuisance species, database, World Wide Web, introduction, spread, impacts, control, Gulf of Maine, Northern Atlantic, Mid-Atlantic, Southern Atlantic, Gulf of Mexico, Pacific Northwest, Great Lakes, information, education, clearinghouse

The National Aquatic Nuisance Species Clearinghouse serves as a major link between the aquatic nuisance species research community and a wide array of end-user audiences, encourag-ing and facilitating the transfer of aquatic nuisance species research information and technology among universities, governmental agencies, industries, and special interests through-out North America and worldwide. The Clearinghouse also plays a high-profile role as a primary nexus for identifying completed, current, and proposed aquatic nuisance species research activities and for linking researchers with similar interests pertaining to important marine and freshwater aquatic nuisance species introduction, spread, research, and policy initiatives.

The Clearinghouse addresses marine and freshwater aquatic nuisance species throughout the Gulf of Maine, Northern Atlantic, Mid-Atlantic, Southern Atlantic, Gulf of Mexico, Central and Northern California, Pacific Northwest, and Great Lakes regions, as well as North American inland river systems, and is the home of North Americaís most extensive technical library of published research and other materials pertaining to zebra mussels (Dreissena polymorpha) and "quagga" mussels (Dreissena bugensis), and is in the process of building libraries on the Atlantic green crab (Carcinus maenas), the Amur River Corbula (Potamocorbula amurensis), the Chinese mitten crab (Eriocheir sinensis), the grass carp (Ctenopharyngodon idella),the Suminoe oyster (Crassostrea ariakensis), Limnoperna fortunei, shipworms (Teredo navalis), the brown mussel (Perna perna), the Asian clam (Corbicula fluminea), the blue mussel (Mytilus edulis), the dark false mussel (Mytilopsis leucophaeata), the Eurasian ruffe (Gymnocephalus cernuus), the round goby (Neogobius melanostomus), the tube-nose goby (Proterorhinus marmoratus), the rudd (Scardinius erythrophthalmus), the spiny water flea (Bythotrephes cedarstroemi), and the blueback herring (Alosa aestivalis). All of the information in the Clearinghouse is accessible to any researcher, agency, industry, utility, student, or other individual or group having need of the information. Most publications in the library can be obtained in hardcopy on interlibrary loan directly from the Clearinghouse.

A new, searchable electronic database of the Clearinghouseís Technical Library Bibliography is now available on the Clearinghouseís World Wide Web home page. Citations include: author(s), title, document source and date, an annotation, whether the document is a journal article or other type of publication, document length, the language in which the document is written, whether the document is available on interlibrary loan from the Clearinghouse or direct from some other source, and the copying/mailing fee if the document is available from the Clearinghouse. The database is keyword searchable (via a 170+ keyword, four level search outline) and plain language full text searchable. Documents which are available directly from the Clearinghouse on interlibrary loan can be ordered on-line by means of a convenient order form at the end of each search result report. The World Wide Web address for the database is: (http://cce.cornell.edu/seagrant/nansc/anslibsindex.htm)

The web site also contains a series of detailed maps charting the range expansion of the zebra mussel and the "quagga" mussel in North America since 1989, as well as information on a number of other informational and educational materials available from the Clearinghouse.

This poster presentation will introduce attendees to the new National Aquatic Nuisance Species Clearinghouse Searchable World Wide Web Aquatic Nuisance Species Database. A laptop computer containing a working copy of the Clearinghouseís entire web site on CD will be utilized, linked to a data projector, to enable attendees to explore the Clearinghouseís web site, especially the searchable database, including being able to perform keyword and full text searches of the database.

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ECOLOGICAL INTERACTIONS OF INVADING ASCIDIANS WITHIN EPIFAUNAL COMMUNITIES OF SOUTHERN NEW ENGLAND

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Key Words: Botrylloides, Styela, Ascidiella, Diplosoma, predation, ascidians, sessile community

Within the last 25 years, four species of sessile marine ascidians, Botrylloides diegensis, Styela clava, Diplosoma macdonaldi, and Ascidiella aspersa, have invaded marine rocky subtidal habitats of New England. Although all three species produce short-lived, poorly dispersing larvae, they have spread over a broad geographic area from Connecticut to Maine. Within this range their local distributions are fairly patchy, as they occur in high abundance at some sites while being rare or absent at similar sites nearby. Since 1987 we have been conducting experimental field studies in Vineyard Sound and eastern Long Island Sound, examining the ecological interactions between these ascidians and the native community. We have found that: (1) adult ascidians transplanted to sites where they are rare or absent survive and grow at rates similar to those found at sites where they are abundant, (2) these ascidians are not inhibited from recruiting onto substrates occupied by native species, (3) at field sites where these ascidians are rare, 1-3 day-old recruits are preyed on by at least three species of very abundant small snails, Anachis lafresnayi, Anachis avara, and Mitrella lunata, (4) juvenile 1-2 week-old Styela were also preyed on by fish, mostly the cunner, Tautogolabrus adspersus, and (5) Botrylloides and possibly Styela seem to escape predation at an earlier age and smaller size than similar native species. From our studies we feel that these species are able to invade local communities because: (1) they have short range larval dispersal that allows them to build up abundant local populations, (2) their recruitment is not strongly inhibited by native sessile species, and (3) they are less vulnerable to predation than similar native species. However, they do appear to be excluded from some habitats such as the more exposed open coast and even when present they seem to become well-integrated into the local communities.

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EARLY LIFE HISTORY OF HEMIGRAPSUS SANGUINEUS, A NONINDIGENOUS CRAB, IN THE MIDDLE ATLANTIC BIGHT (USA)

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The Japanese shore crab, Hemigrapsus sanguineus (de Haan), was recently introduced to the northeast coast of the USA. The crab has established intertidal populations extending throughout the Middle Atlantic Bight. This study defines early-life-history characteristics that are germane to range extension in this species. Results of the investigation showed that the spawning season of H. sanguineus continues for at least 4 mo in the southern Middle Atlantic Bight. This is considerably longer than the spawning seasons of co-occurring native crabs. Eggs hatch about 14 d after extrusion, and females have the potential to produce several broods each year. Zoeal larvae are tolerant of a wide range of temperature/salinity combinations, and mean duration of zoeal development ranges from approximately 16 d at 25 degrees C to 55 d at 15 degrees C. At 25 degrees C zoeae are capable of development to the megalopa stage at salinities as low as 15 parts per thousand. At lower temperatures the zoeae require salinities above 20 parts per thousand. The megalopa stage appears to have more stringent temperature/salinity requirements, which may restrict H. sanguineus to rocky shores of the coastal ocean and the adjacent high-salinity regions of the estuary. Under these conditions megalopae molt to the first juvenile stage in approximately 25 d post hatching. Newly metamorphosed crabs reach the fifth juvenile instar in 35 d. Dry-weight growth of zoeal larvae and early stage juveniles is exponential at respective rates of 23 and 8 % of body weight per day.

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FILTRATION MECHANICAL TEST RESULTS FROM THE GREAT LAKES BALLAST DEMONSTRATION PROJECT

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Key Words: ballast water filtration, nonindigenous species introductions, filtration efficiency

The Great Lakes Ballast Demonstration Project has been investigating the effectiveness of automatic backwash screen filtration of ballast water during intake as a means of minimizing the potential for the future introduction of nonindigenous species through the ballast water vector. The Great Lakes Protection Fund, Legislative Commission for Minnesota Resources (LCMR), a collaboration of Federal agencies, and universities have supported the project. The initial testing in the 1997 operating season involved target of opportunity testing onboard a Seaway-sized bulk carrier M/V Algonorth during operations between the Gulf of St. Lawrence and Great Lakes ports. This testing provided important information on system design, operation, and biological effectiveness, but the mechanical test results were of limited value as benchmark experiments. During the summer of 1998, the modular installation was moved to a barge for more controlled, intensive testing in the Duluth-Superior Harbor, while the M/V Algonorth was out of service waiting for cargo. The overall design of the shipboard and barge ballast water filtration installations will be summarized. The results from the filtration mechanical test program will be reported. The program included extended testing with 25 micron, 50 micron, and 100 micron filters following an operating profile approximating expected normal shipboard operations. Lessons learned in the overall system design, development, and test program will also be presented.

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LARVAL EXPERIENCE CAN INFLUENCE INVASION POTENTIAL FOR MARINE INVERTEBRATES

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Marine invertebrate larvae may be transported large distances in ship ballast water and then discharged into a remote location. Planktrophic larvae are likely to be food-limited during ballast transport, while competent larvae, whether they are feeding or nonfeeding, may delay their metamorphosis until after discharge into the new habitat. Food limiting larvae of the gastropod, Crepidula fornicata, resulted in significantly reduced juvenile growth rates. Delaying the metamorphosis of the barnacle, Balanus amphitrite, and several bryzoan species caused similarly reduced rates of growth or colony development. Delaying metamorphosis of the polychaete, Capitella sp. I, resulted in reduced postsettlement survivorship. Differential sensitivity of larvae to these and other sublethal stresses may play important roles in determining the competitive ability of--and the likelihood of successful invasion by--transported individuals.

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POLYDORA CORNUTA BOSC, 1802 (POLYCHAETA: SPIONIDAE): WORLD WIDE INVASION

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Key Words: world wide invasion, Polychaeta, Spionidae, Polydora cornuta

A spionid polychaete, Polydora cornuta Bosc, 1802 (formerly known as Polydora ligni Webster, 1897), is recorded for the first time from the western Pacific: Russia (the Sea of Japan) and Taiwan, and from Brazil in spite of numerous investigations of polychaetes in these countries. Two specimens of the species were found in 1994 in Peter the Great Bay, Sea of Japan, fouling shells of the scallop, Mizuhopecten yessoensis (Jay). No other specimens have been collected in the area since then. Whether one immigration event has taken place or if a continual invasion to the Sea of Japan is occurring is unknown. Numerous reproducing specimens of the species were found off western coast of Taiwan in 1996 and in Paranagu Bay, Brazil in 1998. In all the cases, the species was found near international seaports, in areas of reduced salinities. It is likely that the species, an oyster killer in North American fisheries, has been transported to new areas in the water-ballast tanks of cargo ships. Being previously reported from east, west and gulf coasts of North America, from Europe, Mexico, Argentina and Australia, P. cornuta becomes one of the world wide spread species. Ecology, reproductive biology, the characteristic features and morphological variability of P. cornuta are discussed. The high degree of polymorphism previously reported for the species is suggested to be due to confusion with other species rather than the individual variability of P. cornuta.

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ECOLOGY AND BALLAST-MEDIATED TRANSFER OF VIBRIO CHOLERAE O1 AND O139

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Key Words: Vibrio cholerae, transfer patterns, ballast water, pathogens, cholera

The large-scale dispersal of ballast water by commercial ships provides a significant vector for the transfer of pathogens. We are studying Vibrio cholerae, the etiological agent of human cholera, as a model system to measure ballast-mediated transfer of pathogens as well as possible ecological and human health consequences. We sampled the ballast water of 15 ships arriving to Chesapeake Bay from foreign ports, and all ballast water originated from coastal regions of the North Sea or Mediterranean Sea. Our analysis showed a high prevalence of two different serovars: O1 (100% of vessels) and the recently emerging O139 (93% of vessels). Vibrio cholerae O1 was found at greater densities than O139. Furthermore, in a comparison of whole water samples (a composite of plankton and bacteria > 0.2 mm) and homogenized plankton samples (plankton > 80 mm), V. cholerae densities were significantly greater in the whole water samples. Analysis of Chesapeake Bay water now indicates the presence of this novel serotype, 0139, previously unreported in U.S. waters. These data suggest that ship-mediated dispersal may play an important role in the emergence and epidemiology of some waterborne diseases.

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REACHING OUT: USE OF THE EXOTIC SPECIES WEB SITE

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Key Words: world wide web, education, outreach

The purpose of the Exotic Species Web Site is to inform and educate the public about marine bioinvasions. The pages within the site cover topics related to specific bioinvasive species, ballast water, and aquaculture. Since becoming public in February 1998 the web site has received over 1000 visits. The Marketwave Hitlist program has been used to track the number of visitors, what internet service provider the visitors use, and which pages are visited. Analysis of traffic over the site provides insight into the interests of the users, what does and does not work for encouraging visitors to view more than one page, and whether there are repeat visitors. The poster highlights the web site, describes the challenges in publicizing the site, and offers information on how data from the Hitlist program has been used to improve the web site.

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THE INCIDENCE OF HEMIGRAPSUS RELATIVE TO SALINITY VALUES IN THE DELAWARE BAY ESTUARY AND THE INLAND BAYS OF DELAWARE

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The Japanesse Shore Crab, Hemigrapsus, is an invasive species well established in the Delaware Bay Estuary (large estuary) but has not been documented in the Inland Bays of Delaware (small estuary). In this study Hemigrapsus crabs were collected at the highest salinity levels and along sampling stations toward lower salinity levels in both the Delaware Bay and the Delaware Inland Bays. Salinity and ambient water temperature values with the incidence of Hemigrapsus were compared between the two estuaries systems.

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PROGRESS IN THE MANAGEMENT AND TREATMENT OF SHIPPING BALLAST WATER TO MINIMISE THE RISKS OF TRANSLOCATING HARMFUL NONINDIGENOUS MARINE ORGANISMS

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Key Words: shipping ballast water, ocean exchange, heating, nonindigenous marine organisms

The movement of some 10 billion tonnes of ballast water in ships internationally each year has been responsible for the translocation and establishment of a significant number of harmful nonindigenous marine organisms in various parts of the world. Notable examples include the zebra mussel (Dreissena polymorpha) in North America, the toxic dinoflagellate (Gymnodinium catenatum) in Tasmania, Australia and the Atlantic comb jelly (Mnemiopsis leidyi) in the Black Sea. Over the past five years, a range of management and treatment options have been assessed in an attempt to minimise the future risks of new introductions. In general, chemical treatments have been discounted for long-term, large-scale use due to the likely costs, safety issues, impracticality and potential residual environmental effects. Some physical treatment options, such as filtration and ultra-violet irradiation show some promise, although practicalities and costs for large-scale use have yet to be demonstrated. Ballast exchange remains the primary treatment option recommended for international use at present. Heating (in conjunction with ocean exchange) using waste heat from the shipís engine has been demonstrated to be effective for some international applications. This presentation will briefly review the current status of the various options with particular reference to the use and efficiency of ballast exchange and heating.

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WHERE NORTH MEETS SOUTH: INVASION OF TASMANIA BY THE EUROPEAN GREEN CRAB AND ITS CONSEQUENCES FOR NATIVE CRABS

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Key Words: Carcinus maenas, green crab, nonindigenous species, predation

Some species have been remarkably successful at invading multiple global sites, but few studies have compared the effects of invasion among these sites. We have been studying the effects of the European green crab, Carcinus maenas, in multiple geographic regions to make such comparisons. Here, we describe effects of this invader on native crabs in Tasmania (Australia), invaded within the past decade, and briefly compare these to effects observed at other sites. During the austral summers of 1997 and 1998, we (1) conducted an intensive survey of decapod crustaceans in shallow water embayments of Tasmania, (2) measured mortality rates of native crabs as a function of C. maenas density, and (3) performed a series of field experiments to test for possible predation of C. maenas on native crabs. Our results indicate direct negative effects of C. maenas on the abundance of two native crabs: Paragrapsus gaimardii and Philyra laevis. Our survey data revealed that southern and southeastern coasts of Tasmania have not yet been colonized by C. maenas, and that native crabs are significantly more abundant here compared to within the invaded area. Mortality rates were also significantly higher for these native crabs in the presence of C. maenas, either in the field or manipulative cage experiments. Our data suggest C. maenas controls the abundance of both native crab species, and these results are similar to effects of C. maenas on a native crab in California.

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MARINE BIOINVASIONS IN THE ROCKY SUBTIDAL ZONE (MASSACHUSETTS 1977-1998)

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Key Words: nudibranch, Tritonia, ascidian, Botrylloides, subtidal

Rocky subtidal communities in Northern Massachusetts, Gulf of Maine, have been studied bimonthly to quarterly for the past 20 years. Surveys by SCUBA divers include photography of marked quadrats, transects to determine predator abundance, and measurement of characteristics of the physical environment. During this time period, there has been an approximate doubling of sea urchin (Strongylocentrotus droebachiensis) population density, and we have observed and documented the appearance and community level effects of several nonindigenous species. The European nudibranch Tritonia plebeia and the colonial ascidian Botrylloides sp., of Pacific origin, have been particularly successful invading species, and have severely impacted indigenous assemblages. Tritonia predation destroyed populations of the octocoral Alcyonium siderium, which have not recovered by 1998. Several other ascidians (Botryllus schlosseri, Styela clava, Diplosoma sp.) have appeared rarely in our photographic samples and do not appear to have developed stable local populations at our study sites, although some are abundant elsewhere along this coast.

Alcyonium removal by Tritonia, and a major increase in sea urchin population density (during 1984-1986), caused most other invertebrates to be cleared from vertical rock surfaces; there was also a local increase in areas covered by crustose coralline algae. Horizontal rock dominated by kelp and foliose red algae (1978-1988) were reduced to coralline-dominated urchin barrens after the urchins expanded laterally in 1989. Botrylloides sp. colonies are now common on rock walls and horizontal surfaces where urchin grazing is continuous; this ascidian may have chemical defenses that deter urchin feeding. The synergistic effects of increasing urchin population density and the appearance of several nonindigenous species, within one decade, caused a major alteration in invertebrate and algal assemblages at these sites and a general decrease in small-scale species diversity. The present high densities of urchins currently favor urchin-resistant spatial dominants, such as the indigenous coralline algae, sea anemones (Metridium senile) and sponges (Isodictya spp.), and certain nonindigenous species (e.g. the ascidian Botrylloides sp.). Reduction in sea urchin population density, as has occurred along the coast of Nova Scotia following epidemic disease, could increase invertebrate and algal biodiversity, although the strong overgrowth competitive ability of Botrylloides may allow it to persist even without heavy urchin grazing.

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HISTORY AND IMPACT OF AN INTERTIDAL INVASION: GREEN CRABS (CARCINUS MAENAS [L.]) IN NEW ENGLAND, 1900-1998

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Key Words: Carcinus, Littorina, predator, climate change, Maine, SST

The range of the green crab, Carcinus maenas (L.), in New England has changed with changing sea surface temperature (SST). In this paper I present (1) an historical review of changes in the distribution of C. maenas in New England since 1900 and (2) new data on expansion of C. maenas in Maine in the 1990ís. I will also discuss the relationship between climate change and expansion of C. maenas, and the impact of green crab expansion on its periwinkle prey.

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CHANGES IN BALLAST WATER BIOTA DURING INTRACOASTAL AND TRANSOCEANIC VOYAGES

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Key Words: ballast water, survivorship, intraoceanic, transoceanic

To develop predictive models of marine invasions, information is needed concerning which inoculants fail as well as which succeed and why. The movement of ballast water in commercial ships is acknowledged as a primary vector for the global transfer of marine organisms, yet surprisingly little is known about the starting composition or abundance of the inoculants or patterns of survival during transit. Data are needed on (1) which taxa start voyages as well as which finish and (2) how survivorship of the ballast water biota varies as a function of physical characteristics of the ballast water, voyage length, and taxa. To this end, we sampled organisms from the ballast water of coal ships at the start and finish of both intracoastal (n = 7) and transoceanic (n = 13) voyages. The domestic vessel took approximately 1.5 d to carry ballast water from Massachusetts to Chesapeake Bay, while the transoceanic vessel took approximately 19 d to travel from Israel to Chesapeake Bay. For both routes, we observed tremendous differences in initial abundances of major taxa (< 10 to > 10,000 per cubic meter of ballast water) and substantial mortality during transit. Within each route, survivorship of different taxa varied both within and between voyages. Copepods, however, typically showed highest survivorship. Overall, survivorship was much lower for the transoceanic voyages (10%) than for the domestic voyages (60%). Mortality is not likely to have resulted from physiological stress due to changing salinity or temperature, because these variables remained relatively
constant throughout the voyages. Instead, other factors such as starvation, predation, mechanical damage during ballast water uptake, toxic compounds in the tanks, and encystment may explain the precipitous decline in numbers.

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THE INFLUENCE OF WATER TEMPERATURE ON INDUCED DEFENSIVE RESPONSES BY AN INTERTIDAL SNAIL TO A INTRODUCED CRAB PREDATOR

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Key Words: phenotypic plasticity, shell thickness, water temperature, Carcinus maenas, Littorina obtusata, Gulf of Maine

Two important goals of invasion ecology are to understand how populations respond to introduced predators and how such responses are modified by environmental conditions over the geographic range of prey. Crab-molluscan predator-prey relationships provide an outstanding system in which to address these questions. Recent transitions in shell form of two intertidal snail species to better defended morphologies have coincided with the invasion of a crab predator (Carcinus maenas) into the Gulf of Maine. Although these adaptive shifts have been attributed to rapid selection by Carcinus, recent experiments have shown that gastropods can alter shell form (e.g., thicken shells) during ontogeny in response to crab effluent. The ability of gastropods to contend with an invading predator over a range of water temperatures, however, is uncertain, because calcium carbonate solubility increases as water temperature decreases. As a consequence, any predator-induced increase in shell thickness could be both physiologically difficult and costly for snails in colder waters. In the Gulf of Maine, water temperatures in the north average 6-8oC colder in spring and summer than those in the south, and previous surveys have shown that northern populations of the smooth periwinkle, Littorina obtusata, are thinner shelled and more vulnerable to crushing than southern populations. To test the influence of water temperature on the degree and cost of a predator-induced phenotypic response, Littorina obtusata individuals collected from a northern (Lubec, Maine) and southern (Manchester, Massachusetts) site were reciprocally transplanted and exposed to two predator treatments (Carcinus effluent, no Carcinus effluent) in field experiments. Regardless of source population or transplant location, snails raised in the presence of Carcinus produced significantly thicker shells than conspecifics raised in the absence of Carcinus. Surprisingly, our data indicate that predator effluent has effects on shell form that are comparable to those resulting from water temperature (geographic) differences. Predator-induced changes were accompanied by trade-offs. Snails raised with Carcinus grew more slowly in terms of shell size and also exhibited significant reductions in tissue mass and tissue growth. Trade-offs were greatest for the northern populations raised in their home site. Thus, while colder water snails maintain the ability to respond to a novel predator, the costs are potentially greater than for warmer water snails. These results will be useful in predicting responses by prey populations to anticipated changes in global climate and community composition. Warming trends evident in the Gulf of Maine and elsewhere will likely expand the species ranges of both prey and predator. This climatalogical phenomenon, in conjunction with increasing rates of biological invasions in marine systems, guarantee that prey populations will be exposed to novel predators.

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PATTERNS OF MARINE BIOINVASION IN NEW ZEALAND AND MECHANISMS FOR QUARANTINE

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Key Words: New Zealand, ballast water, mid-ocean exchange, hull fouling

Recent trends in marine invasions to New Zealand, especially from Asia are briefly described in relation to changing trade patterns. Since the 1960ís, when emphasis on trade shifted from the United Kingdom to Asia, there has been an associated increase in the proportion of Asiatic species amongst recently discovered invaders. Notable species include the Pacific oyster, the Asian date mussel, Musculista, and the Asian kelp, Undaria.

The likelihood of new invasions from neighbouring Australia and from Asia via ballast water is discussed in terms of geographic proximity and sea trade. Our preliminary studies suggest it is only a matter of time before further well known invaders such as the Northern Pacific seastar and the European green crab arrive in our ports - if they are not already established. While it appears generally accepted that ballast water is the primary mechanism of trans-oceanic dispersal, the role of other mechanisms should not be ignored. Of particular concern are the periodic events when ships, laid up for long periods in foreign harbours, arrive in NZ waters with heavily fouled hulls. If these vessels are cleaned by divers at the wharf-side, or are again laid up for a long period, then new invasions are likely to occur.

At a national level, the problems of internal quarantine to prevent the spread of unwanted species from "infected" harbours and ports are considered, particularly in relation to the practicalities and effectiveness of ballast water exchange in coastal waters.

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FOOD WEB AND CONTAMINANT FLOW EFFECTS OF AN EXOTIC BIVALVE IN SAN FRANCISCO BAY, CALIFORNIA

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Key words: ecosystem, bivalves, contaminants, food web

The introduction of the Asian clam, Potamocorbula amurensis, into San Francisco Bay has resulted in changes to the benthic community structure, food web, and transfer of contaminants within the ecosystem. The large declines in phytoplankton biomass coincident with the introduction of P. amurensis is shown to be due to "over-grazing" by these filter-feeding bivalves. We estimate that the water column is passed through the northern bay clam populations in excess of twice a day which leads to an imbalance in phytoplankton growth rate (doubling less than once per day) and filter-feeder consumption rate. Other sources of particulate organic carbon (e.g. detritus, bacteria, and bacteria on particles) may also be declining due to grazing by P. amurensis. Estimates of the amount of food consumed by the P. amurensis populations in northern San Francisco Bay are considerably higher than the amount of food available from the phytoplankton. Because northern San Francisco Bay has never had high primary production, it is likely that detritus and bacteria have always been important food for secondary producers. It is unknown what percentage of this food source is consumed by P. amurensis and how this reduction might affect other levels of the food web. We have begun to see some food web responses to the reduction in primary producers and other carbon sources. Populations of the opossum shrimp (Neomysis) and several zooplankton species, all important food species for larval and adult fish, have declined coincident with the invasion of P. amurensis.

The increase in benthic biomass in the northern bay is also changing the flow of contaminants through the ecosystem. Because of the small benthic biomass in the northern bay prior to the arrival of P. amurensis, the food web was dominated by pelagic forms. Although pelagic predators (e.g. mid-water fish, dabbling ducks) may have lost a primary food source, bottom feeding predators (e.g. sturgeon, diving ducks) now have an enhanced food source. However, because P. amurensis has been shown to be a bioaccumulator and biomagnifier of trace elements (e.g. Cd and Se) this shift in the food web may ultimately prove to be detrimental to the bottom feeding predators. Concentrations of some trace elements have begun to accumulate at harmful concentrations in the sturgeon and diving ducks since the appearance of P. amurensis.

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MARINE BIO-INVASIONS: TAKE-HOMES FROM TEN YEARS OF MANAGING THE PROBLEM IN AUSTRALIA

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Australia has been actively researching and developing management strategies for invasive marine species since the mid-1980s, following the discovery by Gustaaf Hallegraeff that the toxic dinoflagellates whose blooms had both economic and human health implications were most likely of foreign origin. The effort against exotic marine species ramped upwards in the mid-1990s with the establishment of the CSIRO Centre for Research on Introduced Marine Pests, a permanent Australian Ballast Water Management Advisory Council (with an associated research body), an Introduced Marine Pest Program in the federal environment department (Environment Australia), and initiatives at the university and state levels. These activities have begun to indicate the real nature and magnitude of the problem, shifting the discussion from media-driven hyperbole to that based a bit more on hard information, while also revealing more clearly the scope for, and constraints on, dealing with exotic marine pests and their vectors. Australian cultural perceptions regarding the 'pristine ocean' are part of a suite of social, political, economic and scientific issues that dictate the direction of current initiatives and set fuzzy, but very real limits on potential management options. These are discussed and their implications considered in the context of where Australian research and management is likely to go over the next few years in developing practical solutions to the 'introduced marine pest problem'.

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PREDICTED IMPACTS OF THE INTRODUCED CRAB, HEMIGRAPSUS SANGUINEUS, IN NEW HAMPSHIRE

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Key Words: Hemigrapsus sanguineus, Carcinus maenas, feeding preferences, gut contents, community structure

The New England rocky intertidal zone has been impacted by several introduced species including the common periwinkle, Littorina littorea, and the green crab, Carcinus maenas. The Asian shore crab, Hemigrapsus sanguineus, is currently established in Massachusetts and is predicted to become established in New Hampshire and Maine. In order to predict the potential impacts of an invasion by H. sanguineus, various aspects of its feeding ecology were examined. An investigation into the algal feeding preferences of H. sanguineus elucidated which algal species are most likely to be negatively affected by herbivory by this crab. H. sanguineus significantly prefers Enteromorpha intestinalis and Fucus vesiculosus in multichoice feeding preference trials, but will consume significant amounts of all species tested when presented in isolation. Gut contents of crabs collected from Massachusetts indicate a primarily herbivorous diet composed of Spartina spp. and algae, with some evidence of omnivory. Feeding preferences of both H. sanguineus and C. maenas on molluscs were assessed to determine potential competitive overlap. Both crab species preferred Mytilus edulis, L. obtusata and L. saxatilis (in descending order) and avoided L. littorea. The pre-invasion community structure of two sites that are likely to be impacted by populations of H. sanguineus was also examined. Quantitative sampling documented the abundance of potential prey (algae, molluscs, barnacles) and potential competitors (C. maenas). Models are presented which illustrate predicted consequences of this crab invasion in New Hampshire.

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ATLANTIC SALMON (SALMO SALAR) IN BRITISH COLUMBIA AND THE BIOLOGY OF INVASION

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Key Words: Atlantic salmon, aquaculture, Pacific Northwest, niche competition, steelhead

Farmed salmon is British Columbiaís largest agri-food export product. Approximately 80% of production is Atlantic salmon (Salmo salar), an exotic species on the Pacific coast. Large scale escapes and small scale "leakage" of adults from marine net pens are not uncommon and lead to over 2600 marine and 150 freshwater reports of Atlantic salmon in B.C. waters in 1997 alone. The continuous addition of free ranging adult Atlantic salmon into the coastal environment combined with the weak state of many native Pacific salmon (Oncorhynchus spp.) stocks has been suggested to enhance the likelihood of colonization. We present preliminary results of our work conducted to delineate what, if any, ecological or genetic impacts are associated with aquaculture escapee Atlantic salmon on native Pacific salmon species. We also present evidence that suggests colonization may be occurring on a Vancouver Island river, an event which would mark the first anadromous expansion of the species beyond its native range.

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IMPLICATIONS OF THE TRANSPORT OF VIABLE PHYTOPLANKTON IN THE BALLAST WATER OF SHIPS

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Key Words: ballast water, phytoplankton, biogeography, exotic species, biological invasion, North Carolina

The spread of exotic species is cited repeatedly as one of the greatest threats to marine ecosystems today. One of the chief transport vectors of non-native aquatic organisms is ballast water discharged from ships. The principal objective of this study was to determine the taxonomic composition of viable phytoplankton species in ballast water collected from ships berthed in the Port of Morehead City, North Carolina, USA. During 1997, a ten-liter volume of unfiltered ballast water was collected from each of nine ships. These ships originated from ports in Japan, Spain, Dominican Republic/ Florida, Belgium, Louisiana and North Carolina. Each sample was filter concentrated, and the live phytoplankton organisms were cultured for 21 days with a range of media and light intensities to simulate different receiving waters. Over 150 genera of viable freshwater and marine phytoplankton were identified from the cultures. Additionally, over 450 more live species morphologies were observed (predominantly protists and unidentified microalgae). These results provide evidence that numerous species of both freshwater and marine phytoplankton are not only viable when discharged in the ballast water of ships, but may also establish successfully reproducing populations. The biogeography of marine phytoplankton species is imperfectly understood; many phytoplankton species are considered globally ubiquitous. Yet, some phytoplankton species are known to have limited distributions. It may be possible that earlier ballast water transfers contributed to the current cosmopolitan distribution of some phytoplankton species. In an effort to reduce the probability of future marine biological invasions, further research needs to focus on the present, as well as historical, capacity of ballast water to homogenize the distributions of phytoplankton species globally.

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FEASIBILITY OF CONTROL BY TRAPPING OF THE EUROPEAN GREEN CRAB, CARCINUS MAENAS, ON MARTHAíS VINEYARD, MA (USA)

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Key Words: Carcinus maenas, control factors, trapping

In response to the threat to publicly maricultured shellfish posed by the invasive European green crab, Carcinus maenas, in embayments on Marthaís Vineyard, MA, several municipalities conduct trapping programs designed to reduce the abundance of this pest, thereby increasing shellfish survival. The presumed benefits of control of the long established green crabs has led to extensive trapping, although the effectiveness of this trapping remains to be tested. Despite large catches, municipal catch records of C. maenas do not suggest obvious decreases in catch per unit effort and/or changes in population structure. Given this experience, we attempt to determine if, in fact, trapping can be effective and, if so, what is the optimum level of trapping. Within each embayment, the adult C. maenas population appears to be relatively closed, although short-term movements within embayments will affect trapping strategy and success. Multi-year data on C. maenas abundance and population structure will be presented to identify seasonal fluctuations. Additionally, trap-independent snorkel surveys are used to evaluate short-term effects of trapping on C. maenas density. Lastly, we compare trapping success of two trap models. Broadly, given the increased need for control of exotic marine pests, the feasibility of trapping programs such as this need to be assessed.

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CAN THE NONINDIGENOUS RED ALGA, PORPHYRA YEZOENSIS, SUCCESSFULLY RECRUIT AND COMPETE WITH LOCAL SPECIES IN EASTPORT, MAINE?

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Key Words: Porphyra, monitoring, Maine

Intentional introductions of species for the purpose of mariculture balance minimizing ecological impact with maximizing economic gain. Coastal Plantations International is in its 8th year of commercially farming an introduced species of nori, Porphyra yezoensis, in Cobscook Bay, Maine. Permits were granted based on the inability of the alga to complete sexual reproduction while under Gulf of Maine temperature regimes. Surveys are being conducted of the intertidal area surrounding the mariculture sites for P. yezoensis recruitment and survival. A preliminary survey conducted in 1996-97 found some evidence of P. yezoensis recruitment surrounding the Mathews Island farm site during the growing season, but there was no evidence of the plants over-wintering. The current study examines the potential for dispersal and establishment of P. yezoensis in the intertidal zone near CPIís nursery farm site at Huckins Ledge. To examine dispersal potential we conducted transect surveys of Porphyra in the associated intertidal areas. In addition, we deployed artificial substrates consisting of synthetic netting used in the commercial growing of nori to enhance Porphyra settlement. These were constructed radially within a kilometer of the farm site and were exchanged seasonally. Porphyra species are collected from the transects and artificial substrates and identified by microscopic examination and isoenzyme electrophoresis. P. yezoensis has not been positively identified in any transect samples to date at Huckins Ledge, however 5 putative P. yezoensis were identified on the artificial substrates in November, 1997. Four of these potential exotics recruited at a single location, and this site effect is being investigated further by examining water flow patterns. To examine the potential for P. yezoensis to survive the winter, seeded net fragments were placed in the intertidal that same November. The existing plants did not overwinter, did not spread to surrounding netting and plant regeneration was not detected by the following March. Laboratory freezing tolerance experiments are being conducted to compare the overwintering ability of P. yezoensis with that of local species. We currently hypothesize that P. yezoensis can recruit ephemerally during CPIís limited summer/autumn farming season, but that it does not survive through the winter and therefore cannot form a permanent established population.

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GEOGRAPHICAL DISTRIBUTIONS AND ORGANISM-HABITAT ASSOCIATIONS OF SHALLOW-WATER INTRODUCED MARINE FAUNA IN NEW ENGLAND

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Key Words: ascidians, bryozoans, crabs, distributions

In the past 20 years, a number of benthic invertebrates have successfully invaded New England coastal waters and are often found as dominant members in these habitats. These include several species of ascidians (Botrylloides diagensis, Styela clava, Ascidiella aspersa, Diplosoma macdonaldi), an encrusting bryozoan (Membranipora membranacea) and the Western Pacific shore crab (Hemigrapsus sanguineus). In order to better understand their potential impact on resident fauna, we conducted broad-scale surveys of coastal habitats ranging from Maine to Connecticut in 1997 and 1998. The primary goal of the survey was to establish the current distributions of the six species and assess habitat types where the species occur and do not occur. Our findings indicate that Botrylloides and Styela are found throughout most of New England; particularly in tidal inlets and embayments. Diplosoma and Ascidiella appear restricted to southern New England, while Membranipora is more commonly found north of Cape Cod. Hemigraspsus has rapidly spread throughout southern New England and was found at several sites in Massachusetts Bay. In general, colonial ascidians appear more common along exposed coastlines north of Cape Cod than in southern New England. Also Botrylloides was frequently found to inhabit the intertidal zone in northern New England. Based on recruitment to floating docks, local populations of the encrusting invaders are well established throughout coastal New England.

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THE IMPACT OF CARCINUS MAENAS ON PATTERNS OF MYA ARENARIA SURVIVORSHIP

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Key Words: Mya arenaria, Carcinus maenas, survivorship, size, burial depth, crab behavior

Studies conducted at the Wells National Estuarine Research Reserve in Wells, Maine evaluated the impact of the invasion of Atlantic green crabs, Carcinus maenas, on the population of native soft-shell clams, Mya arenaria. Field experiments conducted in the Little River estuary investigated differences in survivorship of clams depending upon clam size, clam density, site, and burial depth. The importance of clam size was tested using plastic flowerpots buried in the mud with each pot containing clams from one of four discrete size classes (5-15mm, 20-50mm, 55-60mm, 65-75mm). Half of the pots were covered with protective mesh (5 mm2) to exclude crabs. Large clams (20-75mm) had high survivorship whether covered with protective mesh or not. Small clams (5-15mm) had low survivorship whether covered with protective mesh or not ($p<0.001$). High survivorship by large clams when protected and unprotected may be due to either clam size or burial depth making them less susceptible to crab predation. Low survivorship by small clams when protected and unprotected may be due to predation by crabs small enough to penetrate the mesh. Crabs small enough to penetrate the mesh were found in both protected and unprotected pots. Within the small size class of clams, survivorship was tested between different clam densities, but no significant difference in survivorship was found between high (50 clams/pot) and low (10 clams/pot) clam densities ($p=0.627$). Also within the small size class of clams, survivorship was tested between different sites within the estuary. The protective mesh was found to be effective at increasing survivorship only at the inlet site ($p<0.01$), which suggests there may be relatively more crabs small enough to penetrate the mesh at the upriver site. Separating clam size from burial depth tested the mechanism responsible for high survivorship by large clams. Large clams were found to have high survivorship in all cases except when not protected at shallow burial depths ($p<0.001$). Low survivorship at shallow depths suggests that deeper clam burial depth, not larger clam size, is the mechanism responsible for high survivorship of large clams. The patterns in M. arenaria survivorship indicate a need for further field work on size distributions and foraging strategies within C. maenas populations. The goal of restoring native clam populations in Maine requires identifying the mechanisms responsible for clam susceptibility through investigating the behavioral ecology of the invasive crabs.

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PREDICTING THE SPREAD OF AN INVASIVE MUSSEL: THE CHANGING ROLES OF COMPETITION AND PREDATION

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Key Words: Mytilus galloprovincialis, eastern Pacific, invasion, ecological resistance

The Mediterranean blue mussel, Mytilus galloprovincalis, is invading rocky shore intertidal communities from California to British Columbia. General factors determining the spread and potential impact of a species are dispersal, physical tolerance, and biotic interactions. How will these factors interact to determine the local distribution of this recent invader? I will present experimental results from two islands in Washington: Tatoosh Island, a high energy site on the outer coast, and Saddlebag Island, a sheltered site in northern Puget Sound. Wave energy differences affect the relative abundances of competitors and predators in the mussel zone of these two islands. Field experiments on Tatoosh suggest that competition with the native congener, M. trossulus, will determine the success of the M. galloprovincialis invasion at this exposed site. In contrast, field experiments on Saddlebag suggest that it is predation by the seastar, Pisaster ochraceous, that will significantly limit this invasion on the sheltered island.

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ECOLOGICAL INTERACTIONS AND IMPACTS OF INVASIVE KAPPAPHYCUS SPP., IN KANEíOHE BAY, A TROPICAL REEF

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Key Words: introduction, macroalgae, Kappaphycus, herbivory, fragmentation, habitat alteration

The importance of understanding the mechanisms and impacts of biological invasions remains crucial in our efforts to preserve biodiversity and to minimize environmental degradation. The invasion of marine and estuarine systems by non-native species is now a widely recognized phenomenon that continues to take place around the world. Studies of biological invasions have documented substantial alteration of pre-existing communities by displacing native species through predation, hybridization or competitive interactions. In comparison to the extensive literature that documents invasions of terrestrial and freshwater habitats, little is known of the history or impact of marine invasions. Quantitative studies and long-term experiments to distinguish the effects of an introduction from natural variation in the marine environment remain rare.

Ecological impacts and interactions of an introduced, invasive red macroalga, Kappaphycus spp., are currently being studied in a tropical reef environment on the Hawaiian Island of Oíahu. Since its introduction in the early 1970ís, there has been little documentation of the algaís density or dispersal from initial site of escape. Recently, however, management concerns have been raised because of its apparent abundance and overgrowth of coral on the reefs. Our goal is to provide fundamental data of the algaís ecological interactions and impacts in order to better manage these macroalgae.

The systematics of Kappaphycus are far from satisfactory because of the large size, robust morphologies, indeterminate growth, phenotypic variability and apparently infrequent sexual reproduction of these organisms. Because individuals can reach up to 5-10 kg in wet weight with bulky fronds extending a meter or more in length, typically only small portions are preserved for taxonomic investigation, and many important features of reproductive morphology and post-fertilization events are poorly known. Initial attempts were made to organize the taxonomy of Kappaphycus according to carrageenan type and morphological characters. Several reinvestigations have taken place since that time resulting in the reorganization of the systematics. The existence of three species, Kappaphycus striatum, Kappaphycus alvarezii, and Eucheuma denticulatum, are known in Kaneíohe Bay, but the relative densities and distributions are unknown at this time.

Preliminary studies have included an assessment of principal herbivores to identify agents for biological control. A 24-h observational survey was conducted in July to identify possible grazers that could crop the biomass of these algae in both high and low percent cover sites. Additional surveys will be conducted in winter and spring to account for possible seasonal changes in grazer abundance. Second, predator exclosure cages have been placed in different reef environments to compare growth rates in grazing and non-grazing conditions.

Preliminary studies have also included an investigation of the reproductive strategy. Kappaphycus spp. rarely reproduces sexually, but possesses the ability to fragment small pieces that can regrow into adults. As a result of the algaís ability to reproduce by

fragmentation, an estimation of the minimum viable fragment size is crucial if eradication attempts are to be successful. In addition, studies have also focused on the ability of the alga to fragment in different wave energy environments in order to obtain a better understanding of the algaís distribution and dispersal capabilities.

Assessment of the effects of algal overgrowth on coral is an additional component of this study. Photostations have been built to provide a means to monitor algae encroaching upon live coral. Photographs are taken monthly and will allow us to observe possible smothering effects and habitat alteration. Initial observations have shown that the alga is able to coalesce into the tissue of the coral, providing a strong means for attachment, and thus allowing the alga to persist in high wave energy environments. The novel substrate and structure the algae provides may permit settlement of epiphytes previously absent, as well as shelter and protection for mesograzers.

Preliminary results of the 24-h observational study suggest that the mesograzer component may play a role in controlling the biomass of the algae. The sea hare, Stylocheilus longicaudus, and the shrimps, Rhynchocinetes spp., Saron marmoratus and Stenopus hispidus were observed on large masses of the algae and possibly scraping off the outer layer. Juvenile parrotfish were also observed biting the tips of the alga. Consumption of the alga is unconfirmed, and controlled studies will be conducted to assess the grazer effect on the biomass of the algae. Results of the predator exclosure study have shown that in the sites where cages have been placed, there is no significant difference between the caged and uncaged treatments. This suggests that in these areas, grazing pressure may be low and Kappaphycus preference may also be low, which may result in its abundance in certain locations. Additional studies will focus on placing cages in sites where previous studies have confirmed high grazing intensity. Initial fragmentation studies have demonstrated that fragments of .28 g have demonstrated positive growth in the field, doubling their mass in approximately 10 days. Future studies will focus on the success of fragments of various sizes in different environments.

The initial results of studies to date suggest that a combination of several characteristics of the algae allow for its success as an invader: phenotypic plasticity that allows for persistence in high and low wave energy environments, asexual reproduction through fragmentation which may increase dispersal capabilities, physiological adaptations which permit coalescence and attachment to substrate, possible chemical and morphological characteristics which lead to low grazer preference. It is our goal to obtain a better understanding of the ecology of the alga as well as to assess any impacts or alterations due to the invasion.

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THE INVASION OF THE CHINESE MITTEN CRAB AND ITS EFFECTS ON FISH PROTECTION FACILITIES

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The Chinese mitten crab is native to the coastal rivers and estuaries of the Yellow Sea. It was first observed in San Francisco Bay in 1992. Subsequent observations in 1994-1996 showed the crab had spread rapidly through the Sacramento-San Joaquin estuary. The mitten crab has undergone an explosive growth in numbers over the past several years with unknown impacts to the Bay-Delta ecosystem.

Fall migrating adult crabs are now interfering with fish salvage operations at State of California and Federal fish collection facilities associated with large water diversion projects in the Sacramento River Delta. The mitten crab invasion has negatively impacted these facilities causing high mortality of fish in collection and transport apparatuses.

The mitten crab is catadromous, i.e., adults reproduce in salt water and the young migrate to fresh water to rear and develop (2-3 years). At maturity, adult crabs make a major spawning migration towards the ocean in fall. In 1998 adult crabs began appearing in early August with number reaching 25,000 -28,000 per day by mid-September. Through January and February of 1998, juveniles crabs (upstream migrants) were observed for the first time also. We expect mitten crabs to occur in even greater densities in 1999, and this species will probably remain an important component of the Delta ecosystem, perhaps forever.

The Sacramento Delta fish facilities must find a way to cope with high numbers of crabs each fall with minimal harm to the fish. During the next year we plan to test various methods for crab exclusion and isolation both in laboratory hydraulic models and under field conditions.

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