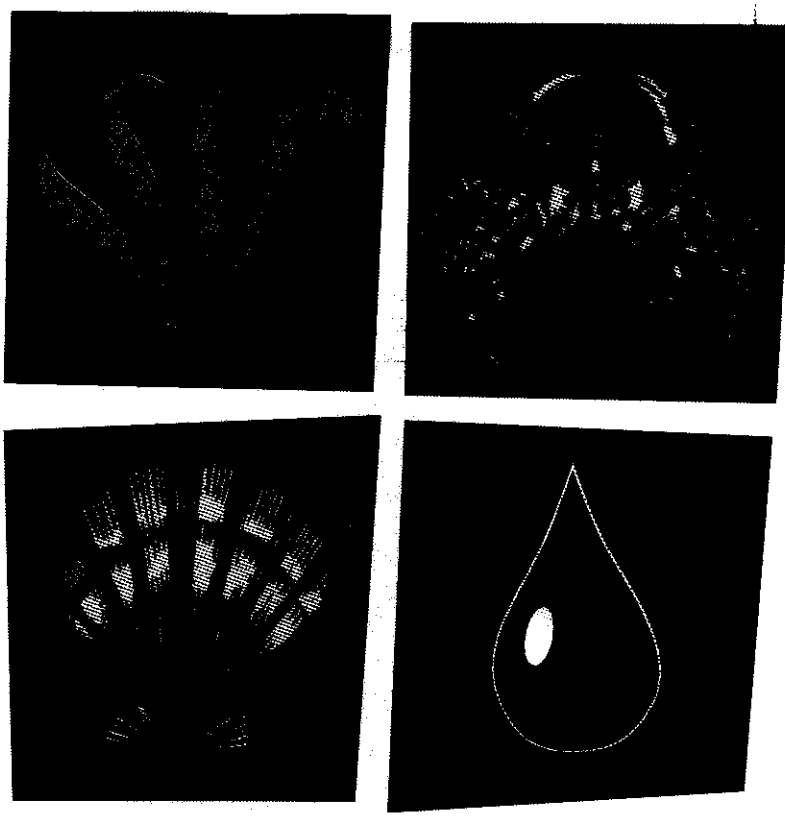
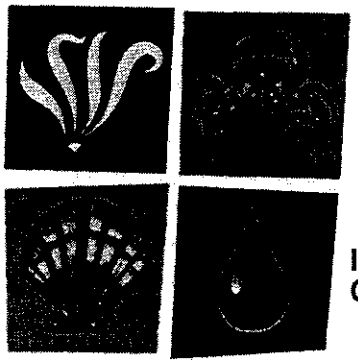


International Conference On

Marine Bioinvasions

April 9–11, 2001
New Orleans, LA, USA

Abstracts



International
Conference On

Marine Bioinvasions

Abstract Booklet

Compiled by
Marilyn Barrett-O'Leary
Louisiana Sea Grant College Program
Louisiana State University
Baton Rouge, LA 70803
Phone: (225) 578-6349
Fax: (225) 578-6331
Email: moleary@lsu.edu

Sea Grant

International Conference On

Marine Bioinvasions

April 9, 2001

Dear Conference Participant:

Welcome to the International Conference on Marine Bioinvasions, to the Gulf of Mexico Region and to the city of New Orleans. You are among a small group of people throughout the world studying various aspects of bioinvasion in the marine and estuarine environments. This conference, convened by the MIT Sea Grant Program and the Louisiana Sea Grant Program, is sponsored by a variety of organizations and agencies sharing your interests and concerns. Representatives of most of these sponsoring organizations (listed on the following page) are attending the conference. Take time to meet them and share your ideas.

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List of Presenters

SPATIAL AND TEMPORAL VARIATION IN PROPAGULE PRESSURE TO CHESAPEAKE BAY

Safra Altman

University of Connecticut

Key Words: Propagule Supply, Ballast Water, Ballast Exchange, Zooplankton

Human-mediated delivery of propagules to coastal marine ecosystems exhibits both spatial and temporal variation, which may drive many observed invasion patterns. Despite the importance of propagule supply characteristics to invasions, many attributes of this supply or propagule pressure remain poorly resolved. Over a seven-year period, we measured variation in plankton communities delivered to Chesapeake Bay in the ballast water of ships, comparing diversity and concentrations of zooplankton as a function of season, source port, voyage duration, and management practices. Each of these independent variables, including ballast water exchange, has a significant effect on propagule delivery. Although delivery of propagules via ballast water is sometimes considered a function of cumulative ship arrivals and ballast water volumes, it is evident that a complex suite of additional attributes is needed to adequately estimate this supply. Measuring spatial and temporal variation in propagule supply remains a challenge to invasion ecology and is key to understanding and preventing invasions.

Author to Contact:
Safra Altman
University of Connecticut
1084 Shennecossett Road
Groton, CT 06340
Telephone: 860-405-9167
Fax: 860-405-9153
Safra.Altman@uconn.edu

AQUATIC INVASIVE SPECIES MANAGEMENT IN MASSACHUSETTS: PROBLEMS WITH DEVELOPING A COORDINATED APPROACH AND THEIR SOLUTIONS

Jason Baker & Jan Smith

Massachusetts Coastal Zone Management & Massachusetts Bay Program

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

The introduction and spread of aquatic invasive species (AIS) poses a serious threat to the marine and freshwater environments of Massachusetts. The proliferation of aquatic invaders has already had a significant impact on the economy and ecology of the Commonwealth, and AIS impacts in other states and countries convey the need to develop a proactive approach to minimizing the introduction and spread of nonindigenous species. This presentation gives an overview of the steps Massachusetts has taken towards a coordinated AIS management strategy, with emphasis on problems encountered along the way (related to both science and policy) and their solutions.

In the fall of 2000, Massachusetts formed the interagency Aquatic Invasive Species Working Group. The AIS Working group has sought to coordinate the patchwork of Massachusetts AIS management activities into a cohesive AIS Management Plan with the goals of 1) educating the public about the AIS problem 2) reducing the potential for AIS introductions 3) controlling the spread of established invaders and 4) minimizing impacts from established invaders. Key elements of this plan include the identification of existing AIS management activities, identification of priority invaders (including established and threatening invaders), and development of a five-year action plan. Major products, objectives, and future management actions which were developed by the AIS Working Group include in the Plan include:
· development of criteria for the designation of priority aquatic invaders;
· identification of priority transport vectors for marine and freshwater systems;
· development of emergency response plans for major taxa of colonizing invaders (i.e. aquatic weeds, shellfish pathogens, bivalves, etc.);
· designation of research priorities for AIS species and transport vectors;
· development of a state-wide AIS database; and
· development of educational tools and programs specific to priority invaders as well as the overall AIS problem.
The Working Group faced various difficulties relating to the coordination of marine and freshwater AIS management efforts, the designation of priority species based on limited research, and the identification of roles and responsibilities of various government agencies during the development of the AIS Management Plan. Thus, the Plan represents the culmination of extensive collaborative efforts between state and federal agencies, biologists, and other natural resource managers. The AIS working group seeks to have a plan approved by the federal Aquatic Nuisance Species Task Force by the fall of 2001 and, with the help of a full time AIS coordinator, begin implementation early the following year.

Authors to Contact:
Jason Baker
Nonpoint Monitoring Coordinator
Massachusetts Coastal Zone Management
251 Causeway St. Suite 900
Boston, MA 02114-2136

Jan Smith
Director
Massachusetts Bays Program
251 Causeway St. Suite 900
Boston, MA 02114-2136

A TALE OF TWO MOLLUSCS

Bax, Nicholas

CSIRO Centre for Research on Introduced Marine Pests

Key Words: Marine Molluscs; Pest Management; Eradication; *Maoricolpus roseus*; *Mytilopsis* sp.

Twenty six species of introduced marine molluscs have been identified in Australian waters (Chad Hewitt, CSIRO, personal communication). Pest management options have been assessed for two of these species - *Mytilopsis* sp., the 'black-striped mussel' that arrived in Darwin in 1998 and *Maoricolpus roseus*, the New Zealand screwshell, that arrived in Tasmania in the 1920s and now forms dense beds on Australia's Southeast continental shelf. *Mytilopsis* sp. was detected within 6 months of its arrival and the decision made to eradicate it as soon as possible. Eradication was achieved rapidly and effectively as *Mytilopsis* sp. was restricted to two (perhaps three) marinas that could be closed off from the adjacent marine environment and poisoned with chemicals. However, continued entry of *Mytilopsis* sp. is occurring - indeed the indications are that entries are increasing - suggesting that we have not seen the last of this mussel. *Maoricolpus roseus*, on the other hand, was not detected by the scientific community until 40 years after its arrival, although scallop fishers had noted its presence many years earlier. *Maoricolpus roseus* now extends across Australia's eastern continental shelf from southern Tasmania to Sydney 1,300 km to the north and from MLW to at least 100 m depth. Control opportunities are limited - the obvious management opportunity is to restrict anthropogenic spread of the screwshell upcurrent and to the west. I use the case histories of these two mussels to examine Australia's responses to marine pest invasions and detail the scientific support that is needed to increase the effectiveness of those responses.

Author to contact:
Nicholas J. Bax
CSIRO Centre for Research on Introduced Marine Pests
GPO Box 1538, Hobart, Tasmania 7001, Australia
phone 61-3-62325341
fax 61-3-62325485
Bax@marine.csiro.au

THE UTILIZATION OF FISHING EFFORT IN CONTROLLING AND/OR CONTAINING CERTAIN MARINE INVASIVE SPECIES

M. Thomas[1], **N. Benjamin**[1], and Z. Grader[2]

[1]Institute for Fisheries Resource (IFR);
[2]Pacific Coast Federation of Fishermen's Association (PCFFA) and IFR

Key Words: Fishing, fishermen, control, containment, harvest

Most of the focus on marine bioinvasions has been on prevention, such as methods of ship ballast water or research on the impacts of invasive species in the aquatic environment where those species have established themselves. This paper will examine potential control and containment methods utilizing fishing gear and equipment (e.g. fishing boats) and fishing men and women). It examines: 1) those species that may be amenable to take by common fishing methods; 2) the types of fishing that may be utilized (e.g. bounty, commercial); 3) the cost benefits, if any, to public institutions of utilizing fishing methods and commercial fishing men/women; 4) the cost considerations of fishing operators in deciding whether to engage in marine invasive species control/containment/eradication efforts; and 5) the institutional frameworks for consideration to ensure fishing methods do, in fact, result in control, containment or reduction of the target invasive species and not the spread of the animal. The authors have all worked in fisheries; Molly Thomas is a biologist and former administrator of the Institute for Fisheries Resources; Natasha Benjamin is the Fisheries Program Officer for the Institute of Fisheries Resources and holds a Masters Degree in Marine Policy; and Zeke Grader is an attorney who has served as Executive Director of the Pacific Coast Federation of Fishermen's Association (PCFFA) for the past 25 years. Both organizations have been active in examining methods of utilizing commercial fishing men and women and their equipment in the control and reduction of certain marine invasive species that threaten native fish and shellfish populations of commercial and recreational importance.

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Author to contact:
Zeke Grader
P.O. Box 29370
San Francisco, CA 94129-0370 USA
phone (415) 561-5080
fax (415) 561-5464
fish4ifr@aol.com

NO LONGER A PRISTINE CONFINE OF THE WORLD OCEAN- A SURVEY OF EXOTIC MARINE SPECIES IN THE SOUTHWESTERN ATLANTIC

Orensanz[1] JM, **Bortolus[2] A**, Casas[1] G, Darrigran[3] G, Elías[2] R, López Gappa[4] JJ, Obenat[2] S, Pascual[5] M, Pastorino[4] G, Penchaszadeh[4] P, Piriz[1] ML, Scarabino[6] F, Schwindt[2,7] E, Spivak[2] ED and Vallarino[2] EA
[1]Centro Nacional Patagónico, Puerto Madryn, Argentina, [2]Universidad Nacional de Mar del Plata, Mar del Plata, Argentina, [3]Universidad Nacional La Plata, La Plata, Argentina, [4]Museo Argentino de Ciencias Naturales "B. Rivadavia", Buenos Aires, Argentina, [5]Instituto de Biología Marina y Pesquera, San Antonio Oeste, Argentina, [6]INAPE, Montevideo, Uruguay, [7]Contact person: CC82, Correo Central, (7600), Mar del Plata, Argentina, schwindt@mdp.edu.ar.

Key Words: Southwestern Atlantic, pristine areas.

The southwestern Atlantic is often regarded as a comparatively pristine confine of the World Ocean. Yet, if man-induced changes in the biodiversity tapestry of coastal seascapes are considered, a closer look at those regions could reveal a different picture could be observed. To that end, we formed an e-discussion group of Argentinean and Uruguayan scientists within which information was exchanged and screened in preparation for a working group meeting that took place concurrently with the 3rd Jornadas Argentinas de Ciencias del Mar (Puerto Madryn, Argentina, September 11-15, 2000). The objectives were: (a) To compile all the evidence about the introduction of exotics in a region of the World Ocean where marine biodiversity is very poorly documented and (b) To develop a holistic, "big picture" of how coastal seascapes of the southwestern Atlantic have changed as a result of ecologically significant invasions. The geographic domain covered by our review corresponds to the coastal zone south of the Brazil/Uruguay border (34o SL), down to the southern end of the continent and its adjacencies (54o SL).
Criteria for Inclusion: (a) species whose "exotic" status is well documented and (b) species that are reasonable candidates to the status of invasive exotics. The second group requires the specification of criteria for inclusion; five were considered: (1) Wide geographic distribution, including "cosmopolitic" species and species showing biogeographically incongruous distribution ranges, (2) Invasive potential indicated by documented exotic status in other geographic regions, (3) The species is abundant in the vicinity of presumable centers of introduction (e.g. commercial harbors), but rare in (or absent from) the rest of the region, (4) Life history suggests high long-distance dispersive potential, particularly for rafting on man-made structures, (5) In the case of species with hard parts, absence from the Quaternary fossil record, which in this region is rich and has been well documented.
Criteria for Exclusion: (a) Anadromous salmonids, as we have concentrated on benthic/littoral organisms, (b) Wood-borers, (c) Species that within the study area are exclusively associated with floating object, (d) Hydrozoa with a medusa stage, (e) Invasive species present only on the freshwater end of estuarine environments and (f) Exotics recorded for Brazil, but not from Uruguay/Argentina.
The emerging "big picture" showed that the impact of recent, human-mediated biological invasions has had, already, a significant ecological impact. Between the most important invasive species detected were: *Ficopomatus enigmaticus*, *Limnoperna fortunei*, *Crassostrea gigas*, *Balanus glandula*, and *Undaria pinnatifida* and one exported invasive species (*Spartina de*nsiflora)
The results are summarized in tables with: (1) 28 species for which the exotic status is well documented and which belong to the following groups: Phaeophyta 1, Polychaeta 4, Mollusca 4, Arthropoda 9, Ectoprocta 5 and Chordata 5, (2) Likely candidates to the exotic status (with 50 species) and they are: Porifera 4, Cnidaria Polychaeta 12, Mollusca 1, Arthropoda 17, Ectoprocta 4 and Chordata 1. (3) Species presumably native to the region under consideration, that have been recorded as exotic in (distant) regions and they are: Porifera 1, Mollusca 2 and Poacea 1.
There are well known cases of species that went exting in a given region, but were later re-introduced by man-mediated Three prominent cases fall in this category: *Crepidula aculeata*, *Petricolaria* (=Petricola) *pholadiformis* and *Balanus amphitrite*.
Our survey of invasions of the southwestern Atlantic by exotic species, the first of its nature for this region, had results unexpected to us at the onset of the project. Most coastal ecosystems between the La Plata River estuary (35º SL) and Golfo Nuevo (43º SL) have been already modified, or are expected to be so in the short term. Only exposed sandy beaches appear to be free from the pervasive ecological impact of biological invasion by exotic species. It is becoming increasingly difficult to establish what the pristine

condition of coastal communities was. The results of the survey reveal that (1) all the four invading animal species that have already had a significant ecological impact tend to concentrate in crowded patches and have pelagic larvae and (2) there is a sharp contrast in the impact of invasive species at equivalent latitudes along the two coasts of southern South America.
Most introductions were accidental, most likely associated with fouled objects or ballast water discharges. We hope that our compilation will assist in the implementation of more proactive policies. Given that the biodiversity of the southwestern Atlantic is among the least known in the World, it is important that scientists and scientific agencies in the region understand the urgency of research on systematic and biogeography.

Author to Contact:
E. Schwindt
CC82, Correo Central
(7600), Mar del Plata
Argentina
schwindt@mdp.edu.ar

STRESS PHYSIOLOGY OF INVASIONS: COMPARISON OF MYTILLUS BAY MUSSELS IN THE CENTRAL CALIFORNIA HYBRID ZONE

Caren E. Braby, Hopkins Marine Station, Stanford University
George N. Somero, Hopkins Marine Station, Stanford University

Key Words: *Mytilus galloprovincialis/trossulus*, temperature, salinity, comparative physiology, stress response

To successfully invade a habitat and establish a viable population, an invasive species must be physiologically poised to cope with the physical environment. However, we know very little about the contribution of physiological adaptation to the success of invaders. The bay mussels in the genus *Mytilus* provide an ideal system for examining differences in physiological strategy between a native and an invasive species because they are closely related and inhabit the same sites. The native species (*M. trossulus*) and the invasive species (*M. galloprovincialis*) have an evolutionary distance of only 3 million years (Vermeij, 1991) and they co-occur, along with hybrids between the two species, in a hybrid zone from Monterey to Cape Mendocino, California. Within the hybrid zone, the proportion of each genotype is variable and the variability does not correlate with a strict latitudinal gradient (Sarver & Foltz, 1993; Rawson, et al., 1999). Mosaic hybrid zones such as this one are thought to be associated with differential physiological adaptation to physical conditions at each site. In the *Mytilus* hybrid zone, the distribution of genotypes correlates with both the salinity and, to a lesser extent, the temperature differences between the sites (Sarver & Foltz, 1993). Through a combination of laboratory experiments and environmental monitoring, I will investigate the connections among physiological adaptation, population genetics and environmental variability at each site. In this talk, I will discuss 1) the variability of the thermal environment of various sites within the *Mytilus* hybrid zone and 2) results from laboratory experiments looking at the differential response of each of the three genotypes to thermal stress and 3) the implications of these results for the observed pattern of invasion and distribution of *Mytilus* in this region.

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Author to contact: Caren E. Braby
Hopkins Marine Station
Oceanview Boulevard
Pacific Grove, CA 93950
phone: (831) 655-6238
fax: (831) 375-0793
e-mail: cbraby@leland.stanford.edu

PHYSICAL HABITAT PROPERTY MEDIATES BITOTIC RESISTANCE TO NON-INDIGENOUS SPECIES INVASION

James E. Byers
University of Washington

Key Words*: Cancer productus*; clams; *Nuttallia obscurata*; physical-biological coupling; predator-free space; soft sediment communities

A soft-shelled non-indigenous clam*, Nuttallia obscurata*, has invaded coastal soft sediment habitats of the northeastern Pacific. In a survey of 35 sites within the San Juan Islands, Washington, USA, Nuttallia was found almost exclusively in sandy substrates, higher in the intertidal than most native clams (> 1m above Mean Lower Low Water). *Nuttallia's* distinctive distribution suggested that tidal height and sediment composition may be important physical factors that control refuges available to *Nuttallia*, regulating its exposure to predation and ultimately the success of its invasion. I tethered *Nuttallia* for 24 hours in the high intertidal where it is typically found and in the low intertidal at an elevation where it was never found. Clams restrained to the surface suffered high mortality from crab predation at both tidal heights, whereas control clams with unrestricted movement exhibited high mortality rates only in the low intertidal. In a second experiment I transplanted sediment within and between the two intertidal heights to measure effects of tidal height and sediment type on *Nuttallia's* survival and burial depth. At both tidal heights all clams placed on mud-cobble substrate, naturally common in the low intertidal, suffered high mortality rates (> 60% in 24 hours). *Nuttallia* on loosely packed sand substrate, naturally found in the upper intertidal, however, survived much better because they buried deeper than in the tightly packed mud. Caged control clams at both tidal heights suffered no mortality. Apparently native predators are mitigating community level impacts of an invader by excluding *Nuttallia* or relegating it to a zone not often inhabited by native species, thereby reducing potential competitive interactions. These findings illustrate that a physical characteristic can mediate biotic resistance to an invader and thus control invasion success and community-level impacts. Generally, such physical-biological interactions may explain some of the reported site-to-site variability in invasion success.

Author to contact: James Byers
Friday Harbor Laboratories
620 University Rd.
Friday Harbor, WA 98250
jbyers@u.washington.edu
Fax: (206) 543-1273

THE POTENTIAL IMPACT OF AND INVASIVE ACOEL, *CONVOLUTA CONVOLUTA*. IN THE GULF OF MAINE

J. Byrnes and J. Witman

Department of Ecology and Evolutionary Biology, Brown University (USA)

Convoluta convoluta is a 2-3mm acoellus turbellarian from Europe that has invaded the Gulf of Maine within the last 5 years. While it has been reported in densities of up to 32 individ./cm^2, its impact remains unknown. In its native habitat it consumes harpacticoid copepods and primary settling mussels <.5mm. This study attempted to estimate worms' potential impact on juvenile mussel populations, as *Myitilus edulis* and *Modiolus modiolus* serve important trophic and structural roles in the Gulf of Maine. We surveyed worm densities in sites of differing exposure over three substrates in order to model patterns of worm abundance. To test the hypothesis that *C. convoluta* was having an ecological impact on primary settling mussels, we preformed lab and field trials to determine worm per capita interaction strength on harpacticoid copepods as an alternate prey item potentially mediating worm impact on mussels. Worm densities varied with respect to depth with their highest densities at intermediate depths, and negatively in correlation to exposure, suggesting a distribution balanced by wave exposure and maximum sunlight exposure. Their consumption rate did not alter mussel consumption rates. While *C. convoluta* consumed up to 20% of primary settling mussels, worm population densities did and per capita impact on juvenile mussels were found to be both highly temporally and spatially variable.

Author to contact:
Jarrett Jaynes
Department of Ecology and Evolutionary Biology
Brown University
Tel: (401) 276-2822
Jarret_Byrnes@brown.edu

EVALUATING BIOEFFECTIVENESS OF FLOW –THROUGH MECHANICAL BALLAST WATER TREATMENT SYSTEMS (CYCLONIC SEPARATION AND UV, AND FILTRATION AND UV) AT THE PILOT- AND FULL –SCALES

A.A. Cangelosi[1], I.T. Knight[2], M. Balcer[3], D. Wright[4], C. Blatchley[5], D. Reid[6], N. Mays[1], and J. Taverna[1]

Northeast-Midwest Institute, Washington DC; [2]James Madison; [3]University of Wisconsin; [4]Environmental Research Services; [5]Purdue University; [6]Consultant (USA)

Key words; ballast, treatment, biological, effectiveness, evaluation

International guidelines and United States law direct ships to manage ballast water to reduce unintentional organism transfers, but the only method currently available to ships, open ocean ballast water exchange (BWE), has serious limitations. Treatment alternatives that are as- or more-effective than BWE have been proposed, but few have been subject to comprehensive bioeffectiveness tests and there is no standard measure of bioeffectiveness. Comprehensive experiments were conducted to describe and compare the bioeffectiveness of two commercially-available ballast treatment combinations: a cyclonic separator (CS) and ultraviolet (UV) system (Hyde-Optimarin), and automatic backwash screen filtration (ABSF) and UV (Ontario Hydro Technologies and Hyde-Optimarin). This paper characterizes results from field tests, and explores ballast treatment characterization and comparison issues, generally**.**

Bioeffectiveness of CS and UV was evaluated at two time intervals following treatment (0 hours and 18-24 hours), two treatment contexts (*MV Regal Princess* installation at 880 gpm, and a large based platform at 1500 gpm), and varied physical/chemical water conditions (Pacific Northwest coastal, and two Lake Superior locations). CS and UV results show effectiveness in killing zooplankton, and attenuating phytoplankton and bacterial growth. Both CS and UV contributed to zooplankton mortality, while UV alone was the dominant component contributing to phytoplankton and bacterial inactivation. The shipboard system, which treated water on uptake and discharge, elevated zooplankton mortality two and a half fold relative to controls. Delayed mortality effects on zooplankton were measurable following treatment during ballasting, while immediate zooplankton mortality was evident upon treatment during deballasting, indicating that the intake treatment, storage in a ballast tank, and a slower pump rate upon discharge could contribute to zooplankton susceptibility to he treatment. Live density of zooplankton in treated water decreased over 90% relative to intake in the shipboard application (compared to 55% in controls). The intake-only treatment on the barge platform (1500 GPM) elevated zooplankton mortality 51% relative to controls. These findings represent a conservative estimate of zooplankton inactivation as latent mortality caused by the discharge treatment. Reproductive effects were not measured, and moribund individuals were counted as live.

CS and UV reduced chlorophyll *a* and bacteria as well, but the CS did not contribute significantly to this effect. Initial chlorophyll *a* concentrations relative to controls were not altered through acute effects of the system such as removal or bleaching on either platform. Storage of the water for 18 hours in a catchment or ballast tank prior to sampling did not alter this finding. The system did reduce algal growth and accelerated die-off relative to controls. Chlorophyll *a* concentrations in incubated samples collected 18 hours following treatment were nearly 60% lower than controls. The system also reduced microbial and MS-2 coliphage concentrations, with UV absorbency strongly influencing system performance. The mean inactivation due to treatment was approximately one log (90%) for bacteria and 1.3 log (95%) for coliphage MS-2 at Two Harbors (UV transmittance over 90%/cm), while the mean inactivation to treatment was approximately 0.1 log (25%) for bacteria and 0.3 log (50%) for MS-2 in Duluth (UV transmittance 30-45%). The mean reduction due to one pass through the treatment system on the *MV Regal Princess* was 82%, but retention for less than two hours in the ballast system raised concentrations of culturable bacteria 1.54 log higher that levels immediately following treatment. Bacterial regrowth and/or repair during 18-24 hour retention in the ballast tank raised bacterial concentrations 2.62 log. Treatment reduced bacteria concentrations more than twice as effectively during discharge than during ballasting.

These results are compared to the effectiveness of ABSF and UV based on barge-platform tests only. UV in combination with ABSF yielded higher (by nearly twice) reductions in live zooplankton than CS and UV, and equivalent reductions in algal and bacterial growth. ABSF alone consistently reduced macrozooplankton by over 95%, and microzooplankton (rotifers) by over 80% relative to controls. The ABSF alone caused up to 30% (average 20%) reduction in initial concentrations of chlorophyll *a*. The treatment achieved much higher reductions in concentrations of specific algal taxa such as dinoflagellates (>97%). The ABSF did not cause an increase in the number of smaller algal fragments due to break-up. However, the ABSF alone may enhance algal growth slightly during retention following treatment through selective removal of grazers, but the increase was not statistically significant. The ABSF alone did not reduce total culturable bacteria, but did reduce attached bacteria concentrations. The effects of ABSF in combination with UV on total culturable bacteria were not different from those of CS and UV.

Clarification of physical/chemical parameters governing treatment performance, and a common performance metric (reduction and inactivation in specific terms) are critical accompaniments of comparable ballast treatment system effectiveness assessments. Understanding the interactions between ballast water treatment processes, and ships' ballast systems, and the receiving system are necessary to differentiate biologically meaningful treatment effectiveness and ostensible treatment effectiveness.

Author to Contact:
Allegra A. Cangelosi
Northeast-Midwest Institute
Washington, DC 20003 USA
Tel: (202) 544-5200
Fax: (202) 544-0043
acangelo@nemw.org

ENGAGING VOLUNTEERS IN BIOLOGICAL CONTROL OF NONINDIGENOUS SPECIES THROUGH THE 4-H NETWORK

Natalie Carroll, Associate Professor, Purdue University
Michael Klepinger, ANS Program Coordinator, MI Sea Grant
Rebecca J. Potratz, Graduate Student, Purdue University
Patrice Charlebois, IL/IN Sea Grant
Dave Voegtlin, Mike Jeffords, and Rob Wiedenmann, IL Natural History Survey
Doug Jensen, MN Sea Grant

Key Words: Volunteers, 4-H, youth, citizen engagement

Overview

A novel approach for enlisting citizen help with the control of purple loosestrife has been successfully instituted. Classroom curriculum teaching students to raise and release Galerucella beetles was adapted for the nonformal youth audience. The curriculum was pilot-tested in three states with 4-H youth groups. The 4-H youth, their leaders, extension educators, and technical experts evaluated the curriculum. Their feedback was used to improve the final curriculum.

Background

Citizen groups are often looked to for assistance when the scope and magnitude of nonindigenous species infestations exceeds the capacity of professionals. Adults are usually enlisted to assist professionals but youth, under the direction of classroom teachers, are occasionally utilized. The guidance of a dedicated teacher with the time and other resources necessary to help control nonindigenous species infestations can be a great benefit to professionals. Due to the increased pressure to teach specific science standards, however, teachers often find it difficult to implement these projects and give time to studies outside the mandated subject matter that they must teach. Many teachers are also finding it increasingly difficult to take their students on the field trips that are required when working with invasive species. Furthermore, unless a school system has year-around-school class may not be in session when the fieldwork needs to be done. For these reasons project personnel decided to look to the nonformal audience for assistance with control of an invasive, nonindigenous species.

Procedure

The nonformal curriculum was based on and adapted from two excellent classroom teaching resources (The Purple Loosestrife Project Cooperator's Handbook (Chapman, D., et. al) and Biodiversity, Wetlands, and Biological Control: Information and Activities for Young Scientists. Purple Loosestrife: A Case Study, Teacher Training manual (Jeffords, M.R. et al.)). Because of the scientific and technical nature of the information it was necessary to use a network that would allow for training, dissemination of information, and continued contact with project groups. The U.S.D.A. Extension system, particularly the 4-H youth component, met these criteria. 4-H youth groups exist in every state. Extension educators guide the work in collaboration with state specialists located at land grant universities and working with other professionals (such as Sea Grant and Departments of Natural Resources). This network provides contacts for information dissemination, feedback, university expertise, and continuing support.

The major challenge in adapting the curriculum for the nonformal audience was the need to reduce the depth and breadth of information presented in the original classroom curriculum. 4-H groups meet much less frequently than conventional classes, sometimes on a weekly, or even monthly, basis. Furthermore, the volunteer leaders working with the youth come from a wide variety of backgrounds. They may have very little scientific training or they may be professional scientists themselves. The amount and depth of material to be presented and discussed must be clear and concise. Although this constraint is seen as problematic to some professionals there are two offsetting features of the 4-H youth audience that make it possible to be successful: first, the volunteer leaders and youth want to do the project and are interested in being involved. The have voluntarily chosen to participate, they are not forced to listen because it is a science class with tests and exams to worry about. Secondly, 4-H uses a "hands-on" approach that many learners find much more interesting and educational than traditional classroom teaching.

Curriculum manuals were developed for a high school aged audience. Youth manuals contain ten "learn by doing" activities. A leader's guide contains the same activities with the correct (or suggested) answers, background information, suggestions for working with high school aged youth, and additional resources.

Draft curriculum was usually presented at a training workshop for volunteer 4-H leaders although in two cases 4-H leaders did not receive training before using the manuals. The workshop included an overview of the problems caused by the invasive species (particularly purple loosestrife), possible control methods, and an introduction to the curriculum. The 4-H leaders used the youth manual and leader's guide in their club meetings with 4-H youth in a number of different ways. Two 4-H leaders used the manuals with existing 4-H clubs (an Entomology and a Soil & Water Conservation club). They included the purple loosestrife biological control activities as an add-on to their existing programming. Another leader, a former high school teacher new to 4-H, started a new project group that focused only on biological control of purple loosestrife. This leader sparked the interest of the local media and had three write-ups in local papers. The youth manual and leader's guide were also used in a summer camp setting with youth ranging in age from upper elementary through middle school and by a parent working at home with her daughter. These leaders reported a high level of youth interest and involvement and in all but one club the youth developed educational displays for their county fairs.

The leaders, extension educators, and youth provided feedback both formally and informally about the usefulness of the manuals, the training workshop, and support they had during the pilot-test phase of the project. Technical experts (Sea Grant and the Natural History Survey) also reviewed the draft manuals and provided feedback. All feedback was used to make improvements to the curriculum. The final curriculum will be submitted to National 4-H for juried review. If accepted by National 4-H the curriculum will be made available to 4-H members and leaders nationwide.

The specific steps that were used in the curriculum development were:
· Connection with people working with biocontrol of nonindigenous species for content, presentation methods, and techniques
· Adaptation of classroom materials for a nonformal audience
· Pilot-test of draft materials in 3 states (IN, IL, MN) through the Extension system (4-H Youth Development)
· Compilation of feedback, evaluation of feedback with project personnel, incorporation of suggestions into the curriculum
· Professional design and layout of curriculum
· Dissemination of materials

The linkage of Sea Grant program experts and the Cooperative Extension system of county educators, 4-H volunteer leaders, and youth offered a unique approach to involving citizens in controlling a local invasive species. Technical and youth development expertise was necessary to create, pilot-test, evaluate, and update the curriculum materials. The collaboratation worked very well in producing a high quality, nonformal curriculum for high school aged youth.

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Author to contact: Natalie Carroll, PhD
4-H Youth Development Department
1161 Agricultural Administration Building
Purdue University
West Lafayette, IN 47907-1161
Phone: (765) 494-8433
Fax: (765) 496-1152
E-mail: ncarroll@purdue.edu

METHODOLOGY FOR ADDRESSING THE PROBLEM OF PATHOGENS IN SHIPS BALLAST WATER

Gloria A. Casale, M.D., MSPH
Healthcare Policy Fellow
Health Resources and Services Administration

Hugh H. Welsh, J.D.
Deputy General Counsel, Port Authority of New York and New Jersey
Chairman, Law Committee, American Association of Port Authorities
Chairman, Committee of Legal Counselors, International Association
of Ports and Harbors

Recent findings give reason to call into question the current analysis of the problem of nonindigenous species and the efficacy of the regulations adopted to deal with the international transport of pathogens. We propose to identify and discuss this problem, demonstrate why the current approach may be ineffectual and suggest a methodology to analyze the problem and develop an effective regulatory solution. The transport of pathogens, organisms that produce disease in plants or animals, as well as nonindigenous species has been recognized and documented within the past few years .

A study recently released by the Smithsonian Environmental Research Center reported that fifteen ships traveling from European and Mediterranean ports to ports in the Chesapeake Bay tested positive for pathogenic viruses and bacteria . Until now, the focus in the United States has been on the ecological consequences of bio-invasions by exotic species with virtually no consideration of the public health implications of the introduction of pathogens. The identification of pathogens among those species being transported now brings into question certain assumptions that have been the foundation of interim measures adopted such as at sea exchange of ballast water. The National Invasive Species Act of 1996 (NISA) directed the Secretary of Transportation to promulgate regulations that (a) require vessel masters to report their ballast water management practices when entering United States waters from beyond the 200 mile Exclusive Economic Zone (EEZ) and (b) describe a regime of voluntary ballast water management practices for use by such vessels. The voluntary guidelines include holding ballast water on board and open-ocean exchange of ballast tanks that will be discharged in United States waters. The purpose of the prescribed management practices was to (1) minimize the transfer of non-indigenous species in ballast water of ships and (2) reduce the risk of exotic species invasions associated with the release of ballast water. Except for one brief mention in the Congressional Record, pathogens were virtually ignored in the discussions of NISA and the regulations adopted pursuant thereto. While it was noted that ballast water capable of transporting mussels and fleas can also transport a human bacterial pathogen such a Vibrio Cholera, neither the Act or the following regulations focused on the public health implications of coastal water contamination by ballast water.

The Interim Report of the National Ballast Information Clearinghouse recently reported that only 20.8% of the vessels that entered United States waters from outside the EEZ filed mandatory reports with the Clearinghouse and of the 3,560 vessels that reported an intention to discharge ballast water only 21.4% reported having conducted a complete mid-ocean exchange of the volume of water to be discharged. It appears that the regulations, which clearly were not intended to deal with pathogens, are being honored in the breach. We suggest that it is necessary to establish a methodology to deal with the problem of pathogens in ballast water using sound scientific principles and effective legal controls.

The current available knowledge is limited to the following: pathogens are being transported in the ballast water of ships; these organisms pose a health threat to many species including humans, marine mammals, fish, mollusks and shell fish; and, these organisms are able to survive in ballast water despite adverse conditions. Increased scientific knowledge is essential before an adequate solution can be formulated. Solutions will require techniques that must rely on complementary scientific and legal disciplines. Proposals that have been made to date have not been successful in removing pathogens from ballast water or for that matter truly addressing the problem of the transport of other non-indigenous species. Some have suggested that at sea exchange, the only solution attempted to be implemented thus far, is less than 100% effective in removing organisms from ballast water, can pose a significant threat to the crew and cargo of ships in heavy seas and may also deposit contaminated ballast into high speed ocean currents with the

potential of causing increased dispersal at areas located "downstream" of reballasting areas. Several individual states have passed statutes that were not based on scientific knowledge or sound technology and present a complex regulatory labyrinth, which interferes with international trade. Currently, research is being conducted to define mechanisms that will decrease the numbers of pathogens and invasive macro species in ballast. We propose that acceptable scientifically sound standards must be established as the foundation of regulations that will encourage the development and application of technological solutions. Until scientific methodology has determined the nature and extent of the problem and the appropriate standards have been developed and codified, no enforcement process can be set in place. Then and only then will an environment be established that will encourage the development of scientifically sound technology.

Author to contact: Gloria A. Casale
Health Resources and Services Administration
Center for Quality
Parklawn Building
5600 Fishers Lane
Rockville, MD 20857
(301) 443-6205
gcasale@hrsa.gov

Hugh H. Welsh
One World Trade Center, 67 East
New York, NY 10048
(212) 435-6915
hwelsh@panynj.gov

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

Tara Casanova, Cedar Island Marina Research Laboratory

KEY WORDS: Exotic, Introduction, Interspecific competion, Japanese Shore Crab, Green Crab

The intentional or accidental introduction of exotic species into North America is a great threat to the integrity of natural communities of plants and animals and to the preservation of endangered species (Carlton 1995). The effects of exotic species in marine systems have not been as well studied, but are potentially of such a magnitude that they may result in profound ecological changes in the structure ocean communities (Carlton and Geller 1993). Long Island Sound has a long history of maritime commerce and it is likely that it's species composition changes yearly because of the release of exotic species that are taken up in this manner. There are more species in Long Island Sound this year than last (Carlton 1985). *Hemigrapsus sanguineus* is now well established and rapidly expanding it's range along the Atlantic coast of the United States from Chesapeake Bay to Cape Cod (Carlton 1995). Williams and McDermott (1990) first recorded *Hemigrapsus sanguineus* in the United States on 24 September 1988 during an invertebrate biology course field trip at Townsends Inlet, Cape May County, New Jersey [39o 07'06"N 70o 43'00"W]. Twenty months later (28 May 1990) an immature female was recovered (McDermott 1991). This second finding suggested that the first record of the species in New Jersey was representative of a population already established in U.S. waters. This discovery provides a unique opportunity to document a major introduction to U.S. waters (McDermott 1991).

Hemigrapsus sanguineus is now extremely abundant on the Connecticut coastline. H. sanguineus is thought to exploit different, but overlapping habitats on cobble and boulder shores in rocky inter-tidal habitats (Fukui 1988). In areas where the Green crab (*Carcinus maenas* Linneus), used to be abundant *H. sanguineus* is the most common observed species. Few *Carcinus maenas* are now found. Changes in abundance and/or distribution may be the result of inter-specific competition between the two species for food and habitat. The focus of this study was to determine the relative abundance of *H.sanguineus* at two specific sites on the Connecticut coastline. The possible inter-specific competition between H. sanguineous and *C. maenas* was determined through studying each species' population density and distribution along the rocky inter-tidal zone at each site.

Two study sites were selected based on their central locality along the Connecticut shore and the large percentage of rocky inter-tidal shoreline, which *Carcinus maenas* and *Hemigrapsus sanguineus* seem to prefer. The two sites chosen were Outer Island, Stony Creek and Hammonasset State Park, Madison
Three transects were laid out at each sampling site delineating each tidal zone: the high inter-tidal zone, middle inter-tidal zone, and low inter-tidal zone. Each transect ran parallel to the water line. Both at Outer Island and Hammonasset State Park each transect were divided into quadrants measuring 1m2. The location of these stations was marked with stakes and through marking specific boulders with paint. Five quadrants at each station were randomly selected for each sampling period at Hammonasset State Park, where at Outer Island each quadrant was sampled at each sampling period.

Sampling at each station was conducted where all the boulders within the quadrant to the underlying gravel within a depth of approximately 5 cm were turned over to hand capture both *H. sanguineus* and other native crab species including *C. maenas*. Crabs were placed in labeled jars upon capture field preserved in a 10% buffered formalin solution until analyzed. The number of crabs for each species recovered from each quadrant was determined. Each crab species was identified through the Guide to the Atlantic Seashore (Gosner) and measured to the nearest 0.1mm with vernier calipers. Each crab species was recorded as a member of relative size categories determined by Yasuo Fukui (1988): less than 9mm were considered juveniles, 9.1mm-18.0mm-small, and 18.1+mm-large (adult). Crabs were then sexed and ovigerous females were determined. Temperature and Salinity for each sampling period at each site were recorded at the beginning of the sampling period using a YSI salinometer.

Results presented in this study clearly showed that *H. sanguineus* is numerically dominant in most areas of the intertidal zone at the sites studied. *C. maenas* were observed but in extremely low numbers at both sampling sites were historical data indicates they were once abundant. No other crab species were found at either Outer Island or Hammonasset with the sampling areas used for the duration of the study. *H. sanguineus* were found in areas of very high concentrations of amphipods throughout the mid and low tidal zones, although whether they have been using these amphipods as a food source is unknown. In areas of dense *Fucus* sp. cover results showed no medium to large male and female size classes of *H. sanguineus* were not found. However, *C. maenas* were present *in Fucus* sp. occupied areas.
The highest total numbers of *H. sanguineus* were distributed from the low to the mid tidal zone at both sampling sites for the May and June sampling periods. A spatial shift towards the mid tidal range was observed during July, August and September sampling periods where numbers were extremely high. For the same period, numbers of crabs in the lower tidal zone decreased. This could be a result of the colder water temperatures in September. This suggests that the largest number of crabs in each size class would shift to higher zones because of possible lack of tolerance for the colder water temperatures. Male and female crabs of the larger class sizes showed little or no spatial preference for any portion of the intertidal region during any sampling period. This could be a result of a higher tolerance for temperature changes as crabs mature and grow larger. There were no differences between larger crab sizes and sex (male vs. female), however with the smaller size classes males were numerically dominant early in the year with females becoming dominant towards September. There were small correlation's between smaller size classes and rock sizes varying between 80-100mm. Here small trends were noticed. As rocks became larger there was absolutely no correlation.

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Author to contact: Casanova, Tara.
Cedar Island Marina Research Laboratory
Clinton, CT 06413
Telephone: 860-669-8681 ext. 19
Fax: 860-669-4157
Taracimrl@aol.com

SMITHSONIAN ENVIRONMENTAL RESEARCH CENTER (SERC)
MARINE INVASION RESEARCH LABORATORY -
RESULTS FROM THE NATIONAL BALLAST WATER INFORMATION CLEARINGHOUSE

Esther Collinetti, Whitman Miller, Kelly Lion, Ashley Arnwine, Betsy Wells, Christine Whitcraft, Gregory M. Ruiz

Keywords: Ballast water, invasion rate, database

As a national center, SERC's Marine Invasion Research Laboratory provides synthesis, analysis, and interpretation of invasion-related patterns for the country. Under the National Invasive Species Act of 1996, the U.S. Coast Guard and SERC created the National Ballast Water Information Clearinghouse to collect and analyze national data relevant to coastal marine invasions. Established at SERC in 1997, the Clearinghouse measures:

· Nationwide Patterns of Ballast Water Delivery and Management. All commercial ships arriving to all U.S. ports from overseas report information about the quantity, origin, possible control measures for their ballast water - a primary mechanism for transfer of non-native marine species throughout the world. At present, SERC receives roughly 20,000 such reports per year. Every two years, SERC provides a detailed analysis and report to U.S. Coast Guard and Congress on the patterns of ballast water delivery by coastal state, vessel type, port of origin, and season. A key issue is the extent to which ships undertake ballast water exchange, a management technique to flush potential invaders out of the tanks prior to arrival in U.S. waters. SERC's analysis is used by U.S. Coast Guard and Congress to assess national needs with respect to ballast water management.

· Rates and Patterns of U.S. Coastal Invasions. SERC has developed and maintains a national database of marine and estuarine invasions to assess patterns of invasion in space and time. This database compiles a detailed invasion history of approximately 500 different species of plants, fish, invertebrates, and algae that have invaded coastal states of the North America. Among multiple uses, the database identifies which species are invading, as well as when, where, and how they invaded; it also summarizes any existing information on the ecological and economic impacts of each invader. Over the long-term, this database will help assess the effectiveness of various management strategies (such as ballast water management, above) in reducing the rate of invasions. More broadly, this information is a valuable resource for many user groups --- from resource managers and scientists to policy-makers and industry groups.

Selected results from the first 18 months of data collection are presented and illustrate what has been learned about commercial shipping patterns and ballast water delivery and management in the United States. Excerpts from SERC's national invasion database illustrate important patterns of invasion in marine and estuarine waters of the United States.

Authors to contact: Esther Collinetti, Whitman Miller
Smithsonian Environmental Research Center
647 Contees Wharf Road
Edgewater, MD 21037
Phone: 443-482-2200
Fax: 443-482-2380
Email: Collinetti@serc.si.edu

PLANNING FOR EDUCATION, RESEARCH AND RISK ASSESSMENT: THE WASHINGTON STATE ANS PLAN

Andrea E. Copping, Kate Killerlain, Nancy J. Lerner

Washington Sea Grant Program, University of Washington

Key words: ANS, education, risk assessment, marine invaders

The Need for a Plan

Marine invasives are entering coastal and estuarine waters at an unprecedented rate largely by human-mediated pathways. While many human activities that affect invasives, such as ballast water exchange, are best addressed through regulation and coordination with industry, other pathways are under the control of individual users. These target groups are best reached through education and outreach efforts. At the same time there is a need to better understand the relative risks that each established or incipient non-native marine species might pose.

The State of Washington developed a draft ANS plan in accordance with National ANS Task Force guidelines in 1998. A significant enhancement to that plan took place in 2000. Under the leadership of WSGP, the subcommittee on Education, Research and Risk Assessment prepared sections of the plan that addressed the need for better public awareness and further scientific enquiry.

Process for Developing a Plan

WSGP developed an innovative process for engaging stakeholders and working through the subcommittee on Education, Research and Risk Assessment. We consulted with user groups who have the potential to introduce and spread marine invasive species, as well as groups most likely to be strongly affected by marine invaders. The process for plan development also included key state legislators and built on existing relationships and ANS planning processes, including cooperation with the Province of British Columbia, Canada. Public educators, university faculty, marine researchers, representatives of the boating community, public aquaria and natural resource managers helped shape the program. The process focused around pathways for introduction, risks of establishment and introduction, target audiences, educational vehicles and important messages.

Setting Priorities for Action

There will never be enough dollars to meet the challenge for all marine invasives; it is important to set priorities, based on the relative risks posed by each pathway, species of concern, and target audience. We have developed criteria to weigh the risks and set priorities among the many possible activities and projects that are under consideration in Washington State. These criteria weigh the potential risk of individual species and pathways; they look at the relative costs and benefits for immediate and longer-term action; and they encourage the development of strategic partnerships.

We will present the criteria we have used for setting priorities and will use examples to demonstrate the critical path for choosing education and research activities of importance to Washington State and the Pacific Northwest. Some of these activities are part of the state's ongoing program, including education, monitoring and research on the European green crab. Others are just starting, such as outreach to the dive and recreational boating community and research on competitive advantages among native and non-native clams in marine protected areas. A number of activities are still under consideration; we will use several to demonstrate the effectiveness of the system.

Author to contact: Andrea E. Copping
Washington Sea Grant Program
University of Washington
3716 Brooklyn Ave NE, Seattle, WA 98105
tel: 206/685-8209 fax: 206/685-0380
Email: acopping@u.washington.edu

AN EXOTIC COPEPOD IN PACIFIC NORTHWEST ESTUARIES

J.R. Cordell[1] and M. Rassmussen[2]

[1] School of Aquatic Fishery Sciences, University of Washington
[2]School of Oceanography, University of Washington

Key Words: estuaries, Pacific Northwest, introduced copepods, food webs

Pacific Northwest estuaries and coastal bays may be especially susceptible to invasion by introduced estuarine zooplankton because they are geologically young, and have low plankton assemblage species diversity, are often sites for ballast dumping, and are increasingly disturbed by human activity. The most likely avenue for ballast water introductions in Pacific Northwest estuaries is via ships arriving from Asia. With increased demand in Asia for northwest wood products (primarily raw logs and wood chips), northwest ports have seen an increasing proportion of ships without cargo (i.e. fully ballasted) in recent years (U.S. Customs, Portland, Orgeon, Reports of Arrival Logs). Eight species of planktonic copepods for Asia, including two species of the genus *Pseudodiaptomus*, have been reported in coastal bays of northern California (Orsi et al. 1983; Ferrari and Orsi, 1984; Fleminger and Kramer, 1988; Orsi and Walter, 1991 Orsi 1995, Orsi and Ohtsuka 1999). A third species of Asian *Pseudodiaptomus*, *P. inopus*, has become established in the Columbia River estuary and smaller estuaries in the Pacific Northwest, probably via introduction by ballast water (Cordell et al. 1992, Cordell and Morrison 1996). Additional estuarine zooplanktonsurveys in 1996 and 2000 indicate that this species has not yet invaded northern California, southern British Columbia, or more inland estuaries in Puget Sound. Unlike the Sacramento-San Joaquin estuary, where a succession of exotic copepods have temporarily changed plankton assemblage (Orsi 1995), areas where *P. inopinus* has been introduced have not exhibited change; species appear stable and a dominant component of the zooplankton. *P. inopinus* can dominate the plankton in tidal brackish areas of estuaries that are utilized as rearing ground for fish such as juvenile salmon and smelt-species that often feed heavily on copepods. In light of declining stocks of Pacific salmon and other estuarine fishes in this region, it is of particular interest to fisheries scientists and managers to determine if the introduction and establishment of this copepod has affected commercially important fish and their endemic planktonic prey.

In August 1998, we initiated a 14-month study of the zooplankton of the Chehalis River estuary (Washington State) to document the biology and ecological relationships of *P. inopinus* in relation to other important planktonic prey organisms, and its availability and use as prey for important fish and invertebrate planktivores. Our results show that (1) another estuarine copepod, *Eurytemora affinis*, is restricted temporally and spatially with regard to its expected distriution in this estuary; (2) *P. inopinus* becomes abundant only in summer-fall after juvenile salmon have passed through the estuary, and did not occur in the diets of salmon and most other fishes from our samples; and (3) *P. inopinus* is an important and sometimes dominant prey of the mysid shrimp *Neomysis mercedis* and juveniles of the caridean shrimp *Crangon franciscorum*.

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Author to Contact:
Jeffery R. Cordell
Wetland Ecosystems Team
Fisheries Science, Box 355020
1122 Boat St.
University of Washington
Seattle, WA 98195-5020 USA
Tel: (206) 543-7532
Fax: (206) 685-7471
jcordell@u.washington.edu

AN INVESTIGATION OF HIGH RISK AREAS ON THE HULLS OF MERCHANT VESSELS FOR THE TRANSLOCATION OF EXOTIC FOULING ORGANISMS

Barry A. Costa-Pierce

Mississippi-Alabama Sea Grant Consortium

Keywords: Salinity tolerant tilapia; tilapiinae; Salton Sea; Gulf of California; Gulf of Mexico

Establishment of exotic fish species has been reported to result from escape from government-led biological control projects, from the aquarist industry, and from aquaculture. Cichlid fishes of the subfamily tilapiinae from Africa (Trewavas 1983) are among the world's most widely distributed exotic fishes. Tilapiine fishes have established in nearly all tropical and sub-tropical freshwater ecosystems to which they have had access. To date, however, invasions of tilapiine fishes have been considered a problem only for the world's freshwater ecosystems. We present data from the USA and review reports from workers worldwide which demonstrate that saline-tolerant tilapiine fishes have established worldwide in estuarine ecosystems to which they have gained access and have the potential to penetrate warm temperate estuaries where thermal refugia exist. We contend that saline-tolerant tilapiine fishes constitute a major threat to the fish communities of the world's estuaries.

One of the most widely distributed exotic fish species is the Mozambique tilapia, *Oreochromis mossambicus*, which was exported worldwide first for the control of aquatic nuisance species (mosquitoes and aquatic vegetation); then for pond aquaculture. *O. mossambicus*, although stenothermal, is euryhaline. Lower lethal water temperature has been reported at 9.5oC. Lethal water temperatures for other tilapiine fishes are: 6.2oC (O. aureus); 10.3oC (*Sarotherodon melanotheron*); and 11.2oC (*Tilapia mariae*). Jennings and Williams (1992) reported S. melanotheron reproducing in at oceanic salinities (33-35 ppt) and able to survive hypersaline (100 ppt) conditions. Costa-Pierce and Riedel (2000) reported an *O. mossambicus* hybrid actively reproducing in salinities >45 ppt in the Salton Sea, California, USA, where they comprise over 50% of the biomass and numbers of the fish community.

Estuaries have been reported as the most anthropogenically degraded habitat type on Earth. Saline-tolerant tilapiine fishes are reported as part of fish communities in estuaries in Australia, Southeast Asia, the Pacific, and the Americas. Two reasons for their success are their high tolerances of poor water quality and disease. In addition, tilapiine fishes have an unusual mouthbrooding behavior and remarkable abilities to migrate long distances with broods, thereby impacting areas far from the source(s) of introduction and spawning. *S. melanotheron* in Africa occupy habitats rich in aquatic vegetation and organic matter in coastal lagoons and estuaries. Faunce and Paperno (1999) reported *S. melanotheron* were 90% of the biomass in an east-central Florida mangrove habitat. Costa-Pierce and Riedel (2000) reported *that O. mossambicus* in the Salton Sea, California, USA, a eutrophic saline lake, dominate the numbers and biomass of the fish community.

Impacts of tilapiine fishes on indigenous species may be through predation on native fish species, competition for food, and disease/parasite infestation. *O. mossambicus* predation on milkfish recruits had a major impact on Pacific atoll ecosystem. A large dietary overlap between *O. aureus* and shad larvae (*Dorosoma* spp) was observed in Texas and Florida. *O. aureus* has been observed to outcompete largemouth bass (*Micropterus salmoides*) for zooplankton depressing growth.

New reports of an advancing tilapia invasion into the estuarine reaches of the Barron and Mitchell Rivers in Queensland, Australia cause concern over the $150 million prawn and barramundi fisheries. The saline-tolerant and reproductively isolated *O. mossambicus* population in the Salton Sea, CA is of special concern to the lower Colorado River estuary and the Gulf of California, Mexico. The recent establishment of the tilapia in the Pascagoula River estuary in Mississippi, USA, could negatively impact the Gulf of Mexico sport and commercial fisheries, one of the most lucrative fisheries in the USA, especially if tilapia established in fish nursery habitats. Lastly, power plant warm water discharges could serve as important

thermal refugia for saline-tolerant tilapia, thereby increasing the invasive potential of this group to temperate estuaries.

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Author to contact:
Barry A. Costa-Pierce
Mississippi-Alabama Sea Grant Consortium
703 East Beach Drive, Ocean Springs, MS 39564
Tel: 228-875-9368
Fax: 228-875-0528
Email: b.costapierce@usm.edu

1991/2001: 11 YEARS OF CAMPAIGNS FOR PUBLIC AWARENESS OF THE *CAULERPA TAXIFOLIA* PROBLEM

COTTALORDA Jean-Michel, MEINESZ Alexandre,
CHIAVERINI Danielle and VAUGELAS Jean de

Key words: *Caulerpa taxifolia*, Mediterranean, public awareness campaigns

Accidentally introduced into the Mediterranean sea in 1984, the tropical alga *Caulerpa taxifolia* did not stop to spread since then. At the beginning of 2001, it was already present at least in 6 Mediterranean countries (Monaco, France, Italy, Spain, Croatia and Tunisia, by order of discovery). The ecological and economic threats related to this invasion incited scientists to organize national and international campaigns of sensitization, research and prevention in different Mediterranean countries.
Financed by local communities, national institutions and ministries as well as European Community programs, leaflets, posters or - recently - web sites, all conveyed the same message: "Wanted *Caulerpa taxifolia*. If you find this seaweed, do not help it to spread and phone us". They provide sea users with precise and updated information on the alga and his expansion. Practical advices invite people to get heavily involved in the control of *C. taxifolia* dissemination. Logos of institutional partners officialize the message and show that authorities are aware of the problem.

Since 1991, 190,000 leaflets and 25,000 posters were edited in 6 languages (French, Italian, Castilian, Catalan, Croatian and English) by our laboratory, and distributed in France, Italy, Spain and Croatia. Other hundreds of thousands leaflets were published and distributed by Tunisia and Turkey institutions, or by Non Governmental Organizations (100,000 by the Lions Club, in particular).

Divers, yachtsmen, fishermen, and port administrators are requested to warn scientists in charge of *C. taxifolia* about any new sighting of colonies. These campaigns enable the establishment and the consolidation of national and international informant networks which are crucial to the yearly assessment of *C. taxifolia* spreading in the Mediterranean sea and to the cartographic follow up of *C. taxifolia* invasion. More than 80 % of known *C. taxifolia* locations were reported by sea users.
Each sighting is verified by scientists. All communication campaigns conducted by our laboratory have been followed by "cartography reports" based on reported sightings. These allow to evaluate, every year (since 1990 in France), the characteristics of the progression of *C. taxifolia* in the Mediterranean sea.

To avoid any loss of information, only one organization (institution or laboratory) should be in charge of collecting new observations in each country. Only one phone number per country (or by large region) should be devoted to calls reception to ensure that all pertinent information is gathered.

The expansion of this invasive species is one of the main element to take into account in the evaluation of the global threat of this alga.
Although it is not possible to precisely evaluate the impact of these prevention campaigns, we may suppose that some sites have and will be probably preserved by the diffusion of thousands of prevention messages.

Author to contact:
J.-M. COTTALORDA
Laboratoire Environnement Marin Littoral
Université de Nice-Sophia Antipolis, Faculté des Sciences,
Campus Valrose, 06108 Nice cedex 2, France
tel.: 0033492076845 - fax: 0033492076849
Mailto: cottalor@unice.fr

AN INVESTIGATION OF HIGH RISK AREAS ON THE HULLS OF MERCHANT VESSELS FOR THE TRANSLOCATION OF EXOTIC FOULING ORGANISMS

Ashley D. M. Coutts and Michael D. Taylor

Cawthron Institute, Nelson, New Zealand

Keywords: Hull fouling, merchant vessels, hull locations, exotic fouling organisms.

Over the past two decades the importance of hull fouling as a major vector for the transfer of marine organisms to new locations has been overshadowed by the importance of ballast water. This has largely occurred due to the preconceived notion that hull fouling has been significantly reduced, if not eliminated, by significant improvements in antifouling paint technology, combined with an increase in vessel speeds and cargo loading times. Coutts (1999) concluded that while such improvements may have reduced the degree of fouling upon merchant vessels, there are still regions upon hulls that remain high-risk areas for the transportation of exotic marine organisms. One such region includes the inside dry docking support strips (InDDSS), which refers to those areas underneath large vessels where chocks are used during dry docking to support the vessel. Reapplication of new antifouling paint is precluded in such areas.

Coutts (ibid) also observed other regions of the hull with high levels of fouling. These were generally protected "nooks and crannies" or irregularities on the hull, which were commonly sheltered from harsh hydrodynamic forces (e.g. rudders, gratings, holes, etc). James and Hayden (2000) also recorded excessive fouling in protected areas upon vessels greater than 500 DWT. This study investigates the importance of protected areas on the hulls of merchant vessels as a mechanism for transferring exotic marine species, and compares these areas with other regions of the hull with respect to the level and diversity of fouling organisms.

In July 1999 a request was made to two commercial diving companies to view their archives of videos of underwater hull inspections of merchant vessels visiting New Zealand. A total of 30 vessels were randomly selected for the study and the video footage was viewed at Cawthron over the following two months. The vessels plyed international and domestic shipping routes and ranged in size from 2,300 to 30,000 DWT. The hull inspections were carried out during visits to one of three New Zealand ports: Auckland, Tauranga and Wellington, between 1998 and 1999. Lloyds surveying regulations ensured that the following regions of the hull were inspected: bulbous bows; bilge keels; InDDSS, Outside DDSS; seachest gratings; propellers; rudders; and rope guards. Video footage of the bow thruster region was restricted to two vessels only, therefore this region was excluded from quantitative analyses.

The percentage cover of fouling organisms within each region was determined by freeze-framing the video at various random locations and recording the taxa that occupied each of 50 random points. A cost-benefit analysis indicated that five quadrants provided sufficient replication for estimating the mean percentage cover of fouling taxa per hull region. Fouling organisms were classified according to three successional categories: category 1 - bare metal, painted surfaces, encrusting brown algae, encrusting green algae, filamentous green algae; category 2 - acorn barnacles, serpulids, coralline algae, encrusting bryozoans, hydroids; category 3 - solitary ascidians, compound ascidians, mussels and oysters (Figure 1).

The hulls of vessels with old (i.e. ineffective) antifouling paint were characterised by fouling organisms in successional categories 2 and 3. Conversely, vessels with new (i.e. effective) paint were characterised by organisms in successional category 1. As expected, the mean percentage cover of algal fouling was highest in the regions receiving the greatest amount of light such as on the bulbous bow, upper edges of the bilge keel, propeller, rudder and rope guards. Very little algae colonized the regions that receive the least amount of light, such as the Outside DDSS and seachest gratings. Coralline algae were very common on the propeller, where antifouling paint was absent. Although the InDDSS was often colonized by some coralline algae, insufficient light levels appeared to limit their success. Corallines were also found on the rope guards and sea chest gratings, but in these regions they were epiphytic.

In addition to algal fouling, the bulbous bow was dominated by compound ascidians, which was probably due to anchor chains removing the antifouling paint whilst the vessels were at anchor. Acorn barncales and sometimes mussels often colonized the sea chest gratings. The InDDSS were also dominated by acorn barnacles, and the rope guards were also sometimes colonized by mussels (Figure 1). The percentage cover of invertebrate taxa overall was highest on the InDDSS, rope guards and sea chests. These regions also had the highest richness of fouling taxa.

Figure 1. Percentage cover of fouling organisms on different parts of the hull within each of three successional categories, as determined by analyses of video footage taken for hull inspections of merchant vessels visiting New Zealand. Values are means ± 1. SE.

Interestingly, Coutts (ibid) found species richness, diversity and evenness amongst invertebrates to be highest on the InDDSS, which supports the findings from the present study. Coutts (ibid) found that 89 percent of the taxa that were present were found on the InDDSS, and 55 percent of the taxa were found only on the InDDSS. The InDDSS were also found to be colonized by three exotic species) yet to be introduced to Tasmanian waters: Megabalanus rosa, M. tintinnabulum, Balanus reticulatus and Watersipora arcuata.

This study has established that certain regions on the hulls of merchant vessels are more susceptible to fouling by exotic marine organisms than are others. The InDDDS, protected areas such as sea chest gratings and rope guards, and regions of the hull that are likely to have the antifouling paint removed by scraping (e.g. the bulbous bow), would appear to pose a higher risk than regions exposed to greater hydrodynamic forces. Targeting fouling surveys and management techniques at such regions might prove to be a cost-effective strategy for minimizing the rate of species transfers via hull fouling. Cawthron is following up the findings of this study with more research into the risks associated with the translocation of exotic marine organisms on vessels' hulls, and comparisons are being made between the significance of hull fouling and other shipping vectors such as ballast water.

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Author to contact:
Ashley D. M. Coutts
Biosecurity Scientist
Cawthron Institute
Private Bag 2, Nelson
New Zealand
Ph +64 3 548 2319
Fax +64 3 546 9464
Email: ashley@cawthron.org.nz

A MODEL FOR IMPROVED VECTOR MANAGEMENT: A CASE STUDY INVOLVING SMALL VESSELS IN SOUTH EASTERN AUSTRALIA

Stuart Craven and Don Hough

Department of Natural Resources and Environment - Victoria, Australia

Key Words: small vessels, fouling, local ports, management

A case study currently in progress involving small vessels operating from ports in southeast Australia is intended to provide a model for improved operational practices for small vessel skippers and crews. It will also assist small/local port managers to reduce the risk of primary and secondary introductions.

The twelve local ports involved in the case study span 1,100 km of coastline and lie in estuarine and marine waters at about 39° South. They are Government owned and managed through delegated committees-of-management (these include Local Government, foreshore managers and a statutory authority). They service local and regional maritime industry and transport needs. In some instances these local ports are co-located or close to larger ports, that serve international trading vessels, that are likely to be the key nodes for the primary introduction of marine pest species by ship-based vectors.

The local ports are both the permanent and seasonal home ports for privately owned vessels used in the fishing industry (for example trawl, pot, aquaculture fisheries), for recreational purposes (mainly fishing and sailing), to service offshore petroleum fields and for charter operations (dive, fishing, and offshore survey).

A consortium of local port operators and users manage the case study to ensure its relevance to, and ownership by, the local community and industry. Vessel movement patterns and the full suite of potential vectors have been qualitatively established for each port. In addition, at eight ports the potential 'vessel-niches' which could be 'infected' with invasive species were identified and rated in terms of their suitability for invasive species, the likelihood that they could be infected and that an infection could be detected. In assessing infection scenarios, priority was given to the entire vessel and its gear. This information was obtained through a series of workshops that called on the practical knowledge of skippers and port managers as well as scientific expertise in hazard analysis and invasive species.

These data will be used to identify vessel practices that can be readily adopted in day-to-day operations, either at the port of origin, at the port of destination or while the vessel is underway. These practices will be disseminated to vessel operators and local port managers in the form of suggested operational guidelines. To assist practical uptake of improved practices it is intended to focus on those practices that are relatively simple, readily applied and robust in their effectiveness.

The Australia-wide application of the case study as model to improve small vessel and local port management is now a priority. Differences in vessels and gear, and local port conditions across Australia will be specific consideration in this process.

Author to Contact: Don Hough
Department of Natural Resources and Environment
GPO Box 500
East Melbourne, 3002, Victoria, Australia.
T (+61) 3 9637 8443
F (+61) 3 9637 8117
Email Don.Hough@nre.vic.gov.au

PROSPECTIVE MANAGEMENT OF THE CHINESE MITTEN CRAB: EVALUATION OF A PASSIVE TRAPPING SYSTEM

Carolynn S. Culver and Mark H. Walter

Marine Science Institute

Key words: control management mitten crab trapping

Despite continued evidence of the negative impacts of introduced marine pests, little, if anything, is being done about already established invaders. Such is the case with the Chinese mitten crab, *Eriocheir sinensis*, which has extensively invaded the San Francisco Bay and associated watersheds. A catadramous species, it lives primarily in freshwater habitats until reaching maturity when it migrates to estuarine habitats to breed. With population estimates in the millions, this species now constitutes a substantial portion of the overall biomass in many freshwater areas. The high abundance of this crab has already caused great economic impacts on fish salvage operations of State and Federal water pumping facilities. Commercial fishermen have also experienced economic losses due to gear and product damage, and the need for additional labor and bait. Further, bank stability is threatened at several sites in the south bay due to the extensive burrowing activities of the mitten crabs. Ecological impacts, including predation of and competition with native species, have also likely occurred given the high abundance, distribution and habits of this crab. However, these impacts remain largely undocumented due to a lack of funding. Importantly, many threatened, endangered and commercially important marine and freshwater species are at risk. For example, mitten crabs have been documented in salmonid and steelhead spawning areas, potentially damaging these troubled populations through habitat destruction and predation on eggs and larvae.

Given the great economic and ecological impacts associated with this species, management strategies are needed. Prospective management techniques may include those that exploit specific migrations associated with the rather complex life cycle of this crab. For example, in order to reproduce adult crabs must migrate from freshwater areas to the bay. We have developed a passive trapping system specifically targeting capture of these migratory adults. This system was developed in collaboration with David Salsbery, Jae Abel and Lisa Porcella of the Santa Clara Valley Water District and involves modification of their existing salmonid monitoring system. Preliminary results are quite promising, as over 10,000 crabs were passively caught in approximately 6 weeks using 2 traps at one site. We will describe the system and the results from our pilot study. In addition, we will discuss the potential use of this system as a control method throughout the San Francisco Bay area.

Author to contact:
Contact Person: Carolynn (Carrie) Culver
Marine Science Institute
University of California
Santa Barbara, CA 93106
Tel: (805) 893-8083
Fax: (805) 893-8062
Email: c_culver@lifesci.ucsb.edu

IMPACT OF INVADING MANGRVES ON HAWAIIAN SOFT-SEDIMENT COMMUNITIES

Demopoulos, Amanda W. J. and Craig R. Smith

Department of Oceanography, University of Hawaii, Honolulu, Hawaii.

Key words: Introduced mangroves, macrofauna, infauna, epifauna, Hawaii

Seven species of mangroves were introduced to the Hawaiian Islands from Florida in 1902 to stabilize the shoreline and provide forage for bees (Wester, 1981; Allen, 1998). At present in Hawaii, large portions of low-energy coastlines as well as the banks of streams and drainage channels are fringed by the red mangrove, *Rhizophora mangle*. *R. mangle* has high dispersal capabilities, broad tolerance, and few natural enemies in Hawaii (e.g., Allen, 1998; Cox and Allen, 1999; Steele et al., 1999); as a consequence, the mangrove habitat appears to be expanding rapidly in Hawaii. Prior to the very recent invasion of mangroves (and other exotic plant species), the intertidal zone of Hawaii lacked vascular plants (Wester, 1981). The introduction of vascular plants, particularly mangroves, to intertidal habitats can dramatically alter a variety of ecologically important characteristics. Mangrove root systems can provide cover from predators, potentially inhibiting top-down control of benthic community structure (cf. Peterson, 1979; Reise, 1985). In addition, mangrove roots extend the availability of solid substrate, providing attachment sites for encrusting fauna such as barnacles and bivalves (Shokita et al., 1989). The root structure of mangroves also baffles water flow, trapping fine and organic-rich sediments transported by currents or produced in situ from mangrove litter (Chapman and Ronaldson, 1958; Bird, 1971). Key environmental parameters altered by mangrove development typically include rates of water flow, sediment granulometry and organic-carbon content, oxygen and sulfide concentrations (both in bottom- and pore-waters), salinity and the availability of hard substrates (e.g., Alongi, 1987a; Robertson and Alongi, 1992). All of these factors can substantially influence the structure and dynamics of soft-sediment communities (see reviews by Pearson and Rosenberg, 1978; Robertson and Alongi, 1992).

In the only published study of the Hawaiian mangrove fauna, Walsh (1963, 1967) indicated that Hawaiian mangroves were a substantially under-utilized habitat. It is important to determine whether this "open niche space" has since been filled by introduced species and/or by native Hawaiian fauna increasingly able to colonize mangrove habitats. To evaluate the impacts of introduced mangroves on Hawaiian macrobenthic communities, we sampled sediments from mangroves and mudflats on the islands of Oahu and Molokai. In addition, we quantified epifauna and epibenthic structures on mangrove roots and the sediment surface using a 0.5 m2 quadrat. Infaunal macrobenthos in saltwater mangrove habitats in Asia, Australia and South America appear to be dominated by oligochaetes, polychaetes, amphipods and molluscs (e.g., Frith, 1977; Alongi and Christofferson, 1992; Lana et al., 1997). Our sampling from mangrove sediments in Kaneohe Bay and the South coast of Molokai, Hawaii, indicated a predominance of oligochaetes, polychaetes, and amphipods. Therefore, the macrofauna currently inhabiting Hawaiian mangroves appears to resemble that of native mangrove forests in other regions. In addition, mangrove roots provide a habitat for introduced species, including the barnacle *Chthamalus proteus*, tilapia (*Oreochromis* sp.) and the Samoan crab (Scylla serrata). The sampled mudflat community was dominated by polychaetes, primarily sabellids. Macrofauna in mangrove sediments were similar to those in mudflats at comparable tidal height, however we found greater infaunal species richness in mangrove sediment habitats. In conclusion, introduced Hawaiian mangroves appear to facilitate the establishment of opportunistic exotics, e.g., the Samoan crab and *Chthamalus proteus*, while concurrently enhancing local species richness.

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Author to contact:
Amanda W. J. Demopoulos (presenter)
University of Hawaii
Department of Oceanography
1000 Pope Road
Honolulu, HI 96822
Tel: (808) 956-8668 Fax: (808) 956-9516
Email: ajones@soest.hawaii.edu

BALLAST WATER TREATMENT AND MANAGEMENT: INACTIVATION OF MICROORGANISMS THROUGH PHOTON ENGINEERING

Dobbs, F.C., Department of Ocean, Earth & Atmospheric Sciences, Old Dominion University
Ball, L., Department of Ocean, Earth & Atmospheric Sciences, Old Dominion University
Doblin, M., Department of Ocean, Earth & Atmospheric Sciences, Old Dominion University
Dyer, F., Industrial Instruments, Inc.
Laroussi, M., Department of Computer & Electrical Engineering, Old Dominion University
Moreira, K., Department of Ocean, Earth & Atmospheric Sciences, Old Dominion University
Wei, Z., Department of Computer & Electrical Engineering, Old Dominion University

Key words: bacteria, dinoflagellates, spores, cysts, ultraviolet light

The economic and ecological threats posed by nonindigenous invertebrate species transported by ships' ballast water are much better documented and understood than the corresponding epidemiological threats posed by the introduction of nonindigenous microorganisms pathogenic to humans, plants, and animals. Current management strategies to limit new invasions associated with ballast water have principally employed at-sea ballast exchange, but this technique is not fully effective in washing out or killing organisms in tanks. It is generally considered that ballast exchange eventually will be complemented or even superceded by a more successful treatment(s). A variety of alternate treatments, including filtration, heating, and application of biocides, are currently being tested. In the case of microorganisms, however, filters can have limited success at best, heat may in fact promote growth of many microbial populations, and biocides may not inactivate resting stages, e.g., spores of bacteria and cysts of dinoflagellates.

Here we present photon-processing technology for the treatment of water in general, and ballast water in particular, with the ultimate intent of greatly reducing its concentration of protozoans, bacteria, and viruses. We have developed a highly efficient and cost-effective prototype reactor designed around a lamp that exposes aquatic microorganisms to germicidal wavelengths and quanta of UV light.

The lamp presents a large area with a cylindrical geometry, is RF-driven, and has a power density in the UV wavelengths of interest between 5 to 8 mW cm-2. To date, we have tested the reactor's killing efficacy on specific microorganisms (the bacteria *Escherichia coli*, *Bacillus subtilis*, and Salmonella *typhimurium*, and the dinoflagellate *Gymnodinium catenatum*) as well as on naturally occurring marine heterotrophic bacteria. We have determined three- to four log reductions in bacterial and dinoflagellate abundance, including spores and cysts, following as little as 30 to 60 second exposures to the UV light; longer exposures have resulted in up to a 7-log reduction, sometimes with no detectable bacteria remaining. We hypothesize that the intense UV lyses cells, as we observe a negative correlation between the optical density of the medium containing the microbes and time of exposure.

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Author to contact:
Fred C. Dobbs
Department of Ocean, Earth & Atmospheric Sciences
Old Dominion University
4600 Elkhorn Avenue
Norfolk, VA 23529, USA
(757)-683-5329 (phone) (757)-683-5303 (fax) fdobbs@odu.edu

INVASION POTENTIAL OF MICROORGANISMS IN SHIPS' BALLAST WATERS

Dobbs, F.C., Department of Ocean, Earth & Atmospheric Sciences, Old Dominion University

Key words: protozoans, dinoflagellates, bacteria, viruses, invasion potential

Our understanding of ballast-water biology is based to a large extent on studies of relatively large (>50 μm), metazoan organisms distributed across a variety of taxa, from polychaetes to copepods to fish. This state of affairs is not surprising, given that most of the public awareness and much of the scientific interest in ballast-water issues was instigated, in North America at least, by the appearance and proliferation of the zebra mussel, a metazoan dubbed by some the "poster child" of aquatic bioinvasions.

Even when microorganisms have been considered, the focus often has been on dinoflagellates, because some of these phytoplankton species have been implicated as players in harmful algal blooms. In contrast, microorganisms other than dinoflagellates have been little studied, yet there are good reasons to consider the invasion potential of other protozoans, bacteria, and viruses. These reasons include their abundance, metabolic diversity, life-history characteristics, range of physiological tolerance, and genetics.

I will discuss each of these above factors with regard to the diverse array of microorganisms in ballast water. When possible, I will present data from ballast-water studies, but insights often emanate from research outside that arena. I will conclude with an evaluation, from a microbial ecologist's perspective, of current and proposed methods for treating ballast water to reduce the risk of introducing nonindigenous species.

Author to contact:
Fred C. Dobbs
Department of Ocean, Earth & Atmospheric Sciences
Old Dominion University
4600 Elkhorn Avenue
Norfolk, VA 23529, USA
(757)-683-5329 (phone) (757)-683-5303 (fax) fdobbs@odu.edu

ASSESSMENT OF TRANSONCEANIC NOBOB VESSELS AND LOW-SALINITY BALLAST WATER AS VECTORS FOR NONINDIGENOUS SPECIES INTRODUCTIONS TO THE GREAT LAKES

Doblin, M.[1], Reid, D. [2], Dobbs, F. [1], Donahue, D. [3], Fahnensteil, G. [3], Jenkins, P. [4], Johengen, T. [5], MacIsaac, H. [6], and Ruiz, G. [7].

[1] Dept. Ocean, Earth & Atmospheric Sciences, Old Dominion University, Norfolk, VA, USA;
[2] NOAA/Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan, USA;
[3] NOAA/Great Lakes Environmental Research Laboratory, Muskegon, Michigan, USA;
[4] Philip T. Jenkins and Associates Ltd., Ontario, Canada;
[5] Cooperative Institute for Limnology and Ecosystems Research, University of Michigan, Ann Arbor, Michigan, USA;
[6] Great Lakes Institute for Environmental Research, University of Windsor, Windsor, Ontario, Canada;
[7] Smithsonian Environmental Research Center, Edgewater, MD, USA.

Key words: ballast water, NOBOB, resting stages, open-ocean exchange, Great Lakes

Over the last decade, much attention has been focused on ballast water as a vector for nonindigenous species introductions, and on open-ocean ballast exchange as a defense against new introductions. However the issue of NOBOB (no-ballast-on-board) vessel operations in the Great Lakes has risen from a position of relative obscurity to become one of the top concerns in the Great Lakes basin today. On average, less than 10% of ocean vessels entering the Great Lakes in recent years contain declarable ballast water on board. NOBOB vessels escape scrutiny under existing U.S. and Canadian federal, state, and provincial laws, yet their ballast tanks may retain residual volumes of unpumpable ballast water, as well as accumulations of sediment representing numerous previous ballasting operations.

Only limited data exist on the presence of biota in NOBOB tanks, but they show that residual water and sediment in these tanks can contain a wide assortment of plants, animals, and microorganisms, including resting stages (Hallegraeff and Bolch 1992; Locke et al. 1993; Galil and Hülsmann 1997; Dickman and Zhang 1999; Hamer et al. 2000). Sediment accumulation can be significant depending on the elapsed time since the ship was last drydocked, and can contain an integrated assortment of organisms from the ballast water that overlayed it from days to weeks earlier, or even months and possibly years earlier in the case of resting stages of organisms.

While operating in the Great Lakes, NOBOB vessels take on water as ballast to maintain their trim and stability. This new ballast water can mix with the residual ballast water, mud, and associated nonindigenous organisms in these tanks and then be discharged as the vessel takes on new cargo at a various ports along its route. Thus, the ballasting operations of NOBOB vessels present a previously overlooked risk as a vector for invasions, but the magnitude of risk remains unresolved.

Another concern is the effectiveness of ballast exchange as a preventative measure against nonindigenous species introductions. Some scientists regard the procedure to be a semi-permeable filter at best (e.g. Locke et al. 1993). Of particular relevance to the Great Lakes is the efficacy of open-ocean ballast exchange when the original ballast is fresh or low salinity water, which differs in density and biota from high salinity water. The freshwater regions of Europe and especially the coastal regions of the Baltic and Black Seas have been implicated as source regions for most of the Great Lakes invaders found since 1985 (e.g. zebra mussel, quagga mussel, round goby, tubenose goby, amphipod *Echinogammarus ischnus*, the fishhook waterflea, *Cercopagis pengoi*, and the *diatom Thalassiosira baltica*; see Ricciardi and MacIsaac 2000). Many of the aquatic organisms found in these regions (a) are euryhaline and can survive exposure to high salinity and (b) form resting stages that accumulate in bottom sediments and are difficult to remove with exchange. Therefore, the effectiveness of exchanging freshwater from these regions for open-ocean saltwater is an important, largely unresolved question to consider when evaluating how well ballast exchange protects the Great Lakes from new invasions.

Fig. 1. Mud accumulation in a ballast tank on a vessel entering the Great Lakes.

We are conducting a multi-disciplinary research program that will improve evaluation of the risks of nonindigenous species introductions associated with ocean-going vessels entering the Great Lakes. Our three interrelated research tasks are:
1. Characterization of biological communities and ballast residuals in NOBOB tanks and relationship to ballast management procedures;
2. Ballast tank mesocosm experiments to determine whether resident biota in NOBOB ballast tanks are discharged to the Great Lakes under actual ship operating conditions;
3. Transoceanic experiments to test the effectiveness of open-ocean exchange.

This poster will provide an overview of this recently initiated program, summarize its objectives and present results from water and sediment samples collected from multiple tanks on a single NOBOB vessel during December, 2000.

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Author to contact:
M. Doblin
Dept. Ocean, Earth & Atmospheric Sciences
Old Dominion University
4600 Elkhorn Ave, Norfolk, VA, USA;
ph. +(757) 683-5980; fax. +(757) 683-5303; mdoblin@odu.edu

DYNAMICS OF MICROBIAL ABUNDANCE IN BALLAST WATER DURING A TRANS-OCEANIC VOYAGE AND THE EFFECTS OF OPEN-OCEAN EXCHANGE

Drake, L.A., Department of Ocean, Earth & Atmospheric Sciences, Old Dominion University
Ruiz, G.M., Smithsonian Environmental Research Center
Mullady, T.L., Smithsonian Environmental Research Center
Galil, B.S., National Institute of Oceanography, Israel Oceanographic & Limnological Research
Friedmann, D.O., National Institute of Oceanography, Israel Oceanographic & Limnological Research
Ball, L.G., Department of Ocean, Earth & Atmospheric Sciences, Old Dominion University
Dobbs, F.C., Department of Ocean, Earth & Atmospheric Sciences, Old Dominion University

Key words: bacteria, chlorophyll a, management, policy, virus

In considering aquatic invasions, the discharge of ballast water from ships is the biggest potential vector for global transport of species. Various treatments to reduce or eliminate the spread of nonindigenous species via ballast-water discharge are being tested, however, the only method now in widespread use is open-ocean ballast-water exchange. In this procedure, coastal water is removed from ballast-water tanks and replaced by oceanic water-either by overflow or by emptying then refilling tanks. Our aims were to evaluate the effects of transport on microorganisms, the numerically dominant organisms in seawater, resulting from transport in ballast-water tanks and exchange in the open ocean. To that end, we rode a coal carrier from Hadera, Israel to Baltimore, USA and collected samples throughout the 19-day voyage to determine the time-dependent concentrations of bacteria, virus-like particles, algal pigments (chlorophyll a and phaeopigments), and total microbial biomass. We sampled two tanks in which water was not exchanged and two in which a 149% exchange was performed on Day 10.

By all measures, concentrations of microorganisms were significantly higher on Day 0 than on Day 15, the last day of sampling. For example, concentrations of chlorophyll a and bacteria in control tanks decreased 26-fold and 2-fold, respectively, throughout the sampling period. Some but not all of the microbial metrics increased following open-ocean exchange. For bacteria, abundances were significantly greater on Day 15 in exchanged water than in unexchanged water. Conversely, algal pigments were significantly higher in unexchanged water than in exchanged water. For virus-like particle abundance and total microbial biomass, there was no difference. Thus, open-ocean exchange of this ship's ballast water did not reduce the abundance of all microorganisms relative to those in control tanks. We stress, however, that the efficacy of open-ocean exchange to reduce invasion by nonindigenous microorganisms can not be evaluated solely by microbial abundances. Species composition and diversity of microorganisms should be considered, but these aspects of ballast-water microbiology are understudied at present. Furthermore, the likelihood of survival by microorganisms discharged with ballast water, a probability critical to evaluating the risk of microbial invasion, remains little investigated. The next step in ballast-water microbiology, therefore, will be to incorporate information on species composition, diversity, and likelihood of survival into descriptive and predictive models applied to efficacy of ballast-water exchange and its verification.

Author to contact:
Lisa Drake
Department of Ocean, Earth & Atmospheric Sciences
Old Dominion University
4600 Elkhorn Avenue
Norfolk, VA 23529, USA
757-683-5060 (phone) 757-683-5303 (fax) ldrake@odu.edu

PERFORMANCE TESTS OF ALTERNATIVE BALLAST WATER TREAMENT SYSTEMS

Michael Dyer
Project Manager, Marine Safety and Environmental Protection Programs
U.S. Department of Transportation, Research and Special Programs Administration, Volpe National Transportation Systems Center
Environmental Engineering Division, DTS-33
55 Broadway
Cambridge Massachusetts, 02142 Robert Hiltabrand, Ph.D.
Program Manager, Marine Systems & Environmental Technology Division
U.S. Coast Guard Research & Development Center
1082 Shennecossett Road
Groton, Connecticut 06340

Craig Taylor, Ph.D.
Associate Scientist, Department of Biology
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

Brain Howes, Ph.D.
Senior Fellow, Center for Marine Science and Technology
University of Massachusetts
New Bedford, Massachusetts 02744

Tom Pedersen
Vice President
Camp Dresser & McKee Inc.
50 Hampshire Street
Cambridge, MA 02139

Key Words: Shipboard ballast water treatment.

The U.S. Coast Guard (USGS) is investigating alternatives to ballast water exchange as a means of reducing the probability of aquatic nuisance species (ANS) transfer. As part of these efforts the USCG has contracted with the U.S. Department of Transportation, Research and Special Programs Administration, Volpe National Transportation Systems Center (DOT) to conduct audits of four shipboard ballast water treatment systems. The audits included observations of the treatment system test operations along with a critical review of the data resulting from the performance evaluation tests conducted by the vendors. Factors that were assessed as part of the audits included the impacts of the treatment system on marine microbiological and biological organisms. Engineering features assessed included operations and maintenance and scale-up factors.

The results of the audit of each of the four different ballast water treatment systems will be presented at the conference. Due to confidentiality agreements the names of the vendors involved in this project cannot be released at this time.

Development of a methodology for efficacy evaluation and standards for testing shipboard treatment systems will be presented as will issues related to onboard ANS management technologies.

Author to contact:
Tom Pedersen
Camp Dresser & McKee Inc.
50 Hampshire Street
Cambridge, MA 02139
Telephone: (617) 452-6272 Fax: (617) 452-8272
e-mail: pedersenta@cdm.com

DISTRIBUTIONS AND ECOLOGICAL IMPACTS OF NON-NTIVE SPECIES WITHIN NATURAL ESTUARINE CHANNELS (POOLE HARBOUR, UK)

Peter E.J. Dyrynda

School of Biological Sciences, University of Wales Swansea

Key Words: exotic, bioinvasion, estuary, ecological impacts

Poole Harbour, located on the central southern coast of England, can be classified as intermediate between an estuary and a lagoon. It features a microtidal range, a single entrance channel and predominantly stable polyhaline salinities. The Harbour is a high-risk environment with respect to NIS. It has long been a centre for molluscan aquaculture, deposits of native oysters and mussels being augmented historically by stocks of exotic shellfish imported directly from continental Europe and North America. The Harbour has served as a sea port for cargo vessels since Roman times and has historical links with North American ports spanning several centuries. Moorings are provided for > 1000 yachts and other recreational vessels, many located within 7 marinas.

Integrated surveys of epibenthos have revealed the great extent of NIS occupancy and influence within the 35 km network of subtidal channels. A dredge survey indicated *Crepidula fornicata* (North America) to be the dominant epibenthic species (wet biomass) followed *by Styela clava* and *Sargassum muticum* (both SE Asia). Dredging, however, under-samples certain important epibenthic species such as the tube-dwelling polychaete *Sabella pavonina* (considered native). A novel cross-channel dive transect technique has revealed complex spatial patterns involving discrete epibenthic communities, governed by long- and cross-channel hydrodynamic gradients (principally involving tidal energy). Current-scoured downstream areas are dominated by mobile sand, gravel and cobble beds colonized by abrasion-resistant epibenthos. Upstream areas are dominated by cohesive muds with heavy sedimentation and minimal epibenthos. Intermediate areas support biodiverse 'forests' of *Sabella pavonina* and also high-density beds of *Crepidula fornicata*. The latter occupy a range of substrata previously dominated by natural beds of the native European oyster *Ostrea edulis*.

Sargassum muticum prevails within clearer water regions of the channel system. In the absence of stable bedrock, plants mainly colonise cobbles and mollusc shells. In summer, large plants are often mobilised by tidal currents, so dispersing their anchoring substrata and epibionts. Dense aggregations of plants may accumulate within low energy areas of the system.

Styela clava occurs as a subsidiary epibiont within all of the aforementioned communities but is most prevalent towards the upstream end of the zone of epibenthic domination where 'islands' of epibenthos occur within soft sediment. A range of other known NIS maintain a more subsidiary presence within the natural tidal channels of the harbour.

Author to contact:
Peter E.J. Dyrynda
School of Biological Sciences, University of Wales Swansea,
Singleton Park, Swansea. SA2 8PP. Wales, U.K. P.Dyrynda@swan.ac.uk

ANTHROPOGENIC INVASION PATHWAYS: PACIFIC ISLAND CASE HISTORIES

Lucius G. Eldredge

Bishop Museum

Key Words: Pacific islands, intentional introduction

Documentation of animals introduced to Pacific islands since European contact is for the most part anecdotal. Long-term, quantitative studies have not been conducted in the marine environment as they have in other areas. However, nearly 100 marine species have been intentionally introduced to Pacific islands. More than 230,000 individual giant clams (family Tridacnidae) have been planted on reefs, not all of these have established themselves. Nearly 75,000 trochus (*Trochus niloticus*) have been transplanted. Thirty-three species of marine fish have been brought to the Hawaiian Islands, mostly for stock enhancement, some accidentally. Eighteen species of introduced marine algae have been identified in the Hawaiian Islands, most being brought in for potential commercial culture. Several parasites, associates, and epiphytes have been introduced along with these species. Pathways, problems, and impacts of these species will be discussed.

Author to contact:
L. G. Eldredge
Bishop Museum
tel: 808-848-4139
fax: 808-847-8252,
psa@bishopmuseum.org

TEMPORAL SIZE DYNAMIC OF AN EXOTIC SHELL, *STROMBUS DECORUS* PERSICUS, IN A PILOT COASTAL AREA OF EASTERN MEDITERRANEAN SEA

Mehmet Betil Ergev and Erhan Mutlu

Institute of Marine Sciences

Key Words: Strombus, size, dynamics, production, Mediterranean Sea.

Size dynamics and annual production and mortality estimates of a non-indigenous marine shell species, Strombus decorus persicus, Swainson, 1821, (first specimens appeared in 1983 before the Israeli and South-Turkish coast. The shell was supposed to be introduced through oil tankers from the Persian Gulf into the Mediterranean. Meanwhile the species has there strongly spread and has also been determined before Cyprus and Rhodes) were studied at 5 and 10 m depth contours (15 min. dredging, mesh size Q=7.5 and U=1.5 cm, mouth width 60 cm) of a Turkish coastal area in the Eastern Mediterranean Sea over monthly sampling from February to December, 2000 (the sampling to be continued). Individual shell length and width, and wet weight including gut were measured. Some samples with tremendous individuals were subjected to sub-sampling. Efficiency of sub-sampling was statistically tested using dispersion index (I). The I values were significant by showing that the sub-sampling was equally efficient. Mean wet weight and abundance varied between 19 (July) and 20 g/m2 (October), and 0.02 (September) and 2.22 ind/m2 (October) at 5 m depth and 0.01 (July) and 2.5 ind/m2 (February), and 25 (May) and 28.5 g/m2 (October) at 10 m. Minimum and maximum shell lengths were measured as 2.5 and 6.2 cm. Two cohorts due to reproduction of the animals were observed from July to September when the sea surface temperature ranged from 27-29 oC. This could be expected case because the shell is tropical (Indo-Pacific) species. The reproduction was less pronounced at 10 m depth. Most of small size individuals appeared at 5 m depth. Intercept values obtained from weight-length relationship were generally found to be greater than 1, which showed the occurrence of the larger organisms at 10 m depth. Growth in shell length as function of sampling days was 0.00051 cm/day/cm at 5 m depth and 0.000048 cm/day/cm at 10 m depth. Total specific production increment (DP) in wet weight was estimated as 6 g/m2 at 5 m and 0.6 gr/m2 at 10 m over a period of 7 months. Total of natural and fishing mortality increment (DM) was 11 gr/m2 and 3 gr/m2 as function of the depths, respectively.

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Author to contact:
Erhan Mutlu*
Institute of Marine Sciences
Middle East technical University
POB 28, Erdemli, 33731, Içel
Turkey
Tel: +90 324 5212406
Fax: +90 324 5212327
e-mail: mutlu@ims.metu.edu.tr

DEVELOPMENT OF STANDARDS AND REGULATIONS FOR THE TREATMENT OF SHIPS' BALLAST WATER

Richard A. Everett

U. S. Coast Guard

The problem of how to reduce the threat of introducing foreign organisms to the waters of the U.S. via ballast water discharged from ships is complex. A number of factors contribute to the complexity of this issue, including: the relative volumes and pumping rates involved in ballasting operations; the great variability in voyage durations and routes; and the great variability in the physical, chemical, and biological characteristics of the ballast water carried by the vessels that operate in U. S. waters.
Under Section 1101 (a) and (b) of the Nonindigenous Aquatic Nuisance Prevention And Control Act, as amended by the National Invasive Species Act of 1996 (NISA), the Congress directed the Coast Guard to issue regulations and guidelines on ballast water management practices to prevent the introduction of nonindigenous species to U. S. waters via the discharge of foreign water from ships' ballast tanks. Under these regulations, mid-ocean ballast water exchange, or environmentally sound alternative ballast water treatment methods, are required for the Great Lakes and Hudson River north of the George Washington bridge and recommended for the remainder of U. S. waters. NISA explicitly directs that such alternative technologies must be determined by the USCG to be "as effective as ballast water exchange" in preventing and controlling infestations of aquatic nuisance species.

.Currently, the actual "effectiveness" of exchange in reducing the threat of introductions is not well resolved. Furthermore, concerns have been voiced that the effectiveness of mid-ocean ballast water exchange as a practice will be inherently difficult to quantify, is not safely practicable on all transoceanic voyages, and is not possible during coastal voyages. Finally, reauthorization of NISA during the 107th Congress may modify the requirements set out in 1996, and may well establish an explicit schedule for the promulgation of regulations. There is thus a need to begin developing standards for ballast water treatment technology and a regulatory process by which proposed alternative technologies will be evaluated and approved.

As with all rule-making efforts by U.S. federal agencies, the first step in the process is one of information gathering. Towards this end, the USCG participated in a discussion within the Ballast Water & Shipping Committee (BWSC) of the federal Aquatic Nuisance Species Task Force that identified four potential approaches to the development of ballast water treatment standards. To gain a better understanding of this issue, the USCG is pursuing a two-pronged approach. First, to get as broad a perspective as possible, a request for comments notice on these approaches and a set of related specific questions has been prepared for publication in the Federal Register in Winter, 2001. Second, to take maximum advantage of existing expertise, a set of focused expert workshops is planned for the spring of 2001. At these workshops, experts in ballast water treatment, ballast water characteristics, and water treatment technology will be challenged to evaluate and further develop options for ballast water treatment standards and protocols for testing ballast water treatment technology. The information gained in response to the Federal Register notice and the expert workshops will be used by the USCG in developing a proposed set of standards and regulations for treating ballast water to reduce the risks of introducing foreign organisms to the waters of the U. S.
In the expectation of future regulatory requirements for ballast water treatment, a number of efforts are underway, in the U.S. and internationally, to develop effective treatment technologies. Both ship owners and technology developers have suggested that a major impediment to full-scale testing of such systems on board operating vessels is the reluctance of ship owners to invest significant time and funds in retrofitting and testing such systems. A major concern of many owners is that regulations established within the near future could require a second expensive fitting. In response to these expressed concerns, the USCG is developing a program through which experimental systems installed on ships will receive conditioned approval for use in-lieu of ballast water exchange. This approval would be granted for a to-be-determined period of time, regardless of regulatory requirements for treatment that might be promulgated during that period. Although the details of the program are not final, it is likely that approval will require the demonstration of some minimal level of effectiveness during tests at smaller scales, and will be contingent

upon the implementation of a rigorous experimental study deemed appropriate by an independent panel of scientists.

The development of ballast water treatment requirements for the U.S. is further complicated by the strong desire to harmonize such regulations internationally. The Marine Environmental Protection Committee (MEPC) of the International Maritime Organization (IMO) is currently discussing a number of issues related to ballast water management. The objective of the MEPC in this regard is to develop internationally accepted ballast water management requirements and guidelines.

Author to contact:
Richard A. Everett, U. S. Coast Guard
Environmental Standards Division (G-MSO-4)
2100 2nd Street, S.W., Washington, D.C., 20593
Tel: (202) 267-2243
Fax: (202) 267-4690
reverett@comdt.uscg.mil

CALIFORNIA'S BALLAST WATER MANAGEMENT AND CONTROL PROGRAM

Maurya B Falkner

Program Manager, California Ballast Water Management and Control Program

California State Lands Commission

Key Words: Ballast Water Management

On October 8, 1999, California's Governor signed Assembly Bill 703, creating the Ballast Water Management for Control of Nonindigenous Species Act (Act), which became effective on January 1, 2000. The Act addresses a problem that has become all the more urgent as international commerce increases resulting in a corresponding increase in the speed with which NAS are being introduced. The introduction of NAS has created ecological, operational, and engineering disasters in many areas of the United States and worldwide. Non-indigenous aquatic species are commonly reported in San Francisco, Los Angeles, San Diego and many smaller harbors and embayments throughout California.

The California Legislature recognized the significance of the problem and established, through passage of the Act, a state program that addresses the issue by making ballast water management mandatory. The law applies to all U.S. or foreign vessels that enter California waters after operating outside the U.S. Exclusive Economic Zone (EEZ). Vessels must either conduct a mid-ocean exchange of ballast water or retain all ballast water on board the vessel. The program also assesses the current condition of the marine environment and evaluates alternative methodology for controlling NAS introduction.

From January 1 through December 31, 2000, 6846 qualifying voyages, by 2300 different vessels have entered California ports. Nearly 50% of these vessel calls are container vessels, 13% each are tank and bulk vessels, with general cargo, auto carriers and passenger vessels each constituting approximately 10% of the vessel calls. Nearly 45% of the vessel calls identify a last port of call (LPOC) as Far East ports such as Japan, China, and the Koreas. Twenty percent of the vessel calls originated from Pacific North American ports in Canada and Mexico, while 13% called at a South American port prior to arriving in California.

Over 7.8 million metric tons of ballast water was discharged into California ports between January 1 and December 31, 2000. Nearly 45% of those vessels discharging ballast in California originated from Far East ports. Interestingly, over 20% came from Mexican ports.

The two California State Lands Commission (CSLC) Field Offices have boarded and inspected approximately 25% of the qualifying voyages during the first 12 months of the Program. Inspections have been on over 1000 different vessels. Each vessel is boarded, paperwork is evaluated, tanks are sampled for compliance and educational material is provided to the ship crew. A report, summarizing the results of the inspection, is provided to the vessel crew. The majority (70%) of those vessel boarded comply with the law. Violations noted are primarily associated with administrative components of the law (incomplete ballast water management plans, no IMO guidelines on board, etc.). Approximately 10% of the violations noted during inspections are associated with the required mid-ocean exchange of ballast water. Of these over 80% are passenger vessels coming from Mexican ports. The CSLC is working with these vessels to identify alternative exchange zones and or management techniques that will ensure compliance with the law in an environmentally sound manner.

Communication among the maritime industry, CSLC and other regulating entities is vital to the success of the California program. Staff has initiated several outreach and educational programs in the past eight months to improve communication among the stakeholders. For example, an updated ballast water web page is found on the CSLC web page. Information on the law, new regulations, and synopsis of meetings, notification of upcoming meetings, and links to other related web pages can be accessed easily. Staff, in conjunction with state and federal agencies and the maritime industry, has participated in or hosted over 10 workshops/conferences on ballast water management in the past eight months.

Beginning in July 2000, the staff initiated a monthly email procedure to notify the maritime industry of vessels that have not submitted the required ballast water report forms. This procedure has been well received by the industry and has resulted in a steady improvement in compliance. The compliance rate for the months of July and August are over 90%.

Finally, the formation, in January 2000, of a Technical Advisory Group (TAG) made up of members of the maritime industry and state agencies has proved beneficial in determining an appropriate fee amount and addressing issues related specifically to the implementation of the California law. The TAG meets quarterly to assess the effectiveness of the Program and the status of the Fund.

CSLC has finalized a Cooperative Agreement with the U.S. Coast Guard to streamline our respective programs. Our goals are to reduce duplicative inspections; data share at the regional and national level and cooperate in research programs addressing new verification techniques and ballast water treatment technology. We are also active members in several ballast water related groups, such as the Pacific Ballast Water Group, Ballast Outreach Advisory Team, and the Pacific Ballast Water Pilot Project. Participants work toward consistent ballast water management regulations on a regional level while sharing data and evaluating alternative exchange zones off shore and feasible treatment technologies.

CSLC staff is working with the technology development sector to identify potential ballast water treatment systems. CSLC is facilitating the transfer of information among the technology development and maritime industries and the state and federal agencies. In August 2000, CSLC was awarded a grant for our proposal titled "West Coast Regional Applied Ballast Management Research and Demonstration Project" from the U.S. Fish and Wildlife Service and National Sea Grant Foundation. In December 2000 the Port of Oakland (POO) generously agreed to match those USFWS funds. The Port of Oakland funds will be used to bring an additional vessel into the West Coast Demonstration Project. Additionally, these moneys will aid in the analysis and subsequent development of standards for ballast water treatment technology.

Author to contact:
Maurya B Falkner
Program Manager
California Ballast Water Management and Control Program
California State Lands Commission
Marine Facilities Division
330 Golden Shore, Suite 210
Long Beach, CA 90802-4246
(562) 499-6312
(562) 499-6317 FAX

UNIT OPERATION SELECTION METHODOLOGY FOR BALLAST WATER – IMPLICATIONS FOR SHIPBOARD OR SHORE-BASED CONTROLS

M. Famoso, E. Voon, J. Sansalone

Civil and Environmental Engineering, Louisiana State University

KEYWORDS: Ballast water control, Ballast exchange, Granulometry, Sediment, Unit Operations

INTRODUCTION: All ballast water management strategies for control of nonindigenous invasive species involves exchange, separation or destruction of these species. Strategies such as open-ocean ballast water exchange and potential concerns associated with this practice have become an accepted ballast water management practice for the control of nonindigenous invasive species (National Research Council, 1996). However, there exist a wide variety of technology-based controls also under consideration. For example, rapid separation techniques involve the physical separation of biological particles and sediment from ballast water and include surficial straining technologies, filtration systems and dissolved air flotation (DAF). These techniques only involve the separation of species, microorganisms and sediment and not necessarily the destruction of this matter. In contrast, mechanical, chemical and inactivation technologies generally result in the destruction of targeted species or microorganisms. This paper examines unit operation-based concepts for physical separation techniques in perspective to the spectrum of controls having potential feasibility for shipboard and possibly shore-based management of ballast water.

BACKGROUND: Effective separation or destruction of suspended nonindigenous invasive species and separation of sediments that also harbor species in a vessel's ballast is challenging. Physical constraints such as large volumetric flow rates, large ballast volumes, time constraints in port or in transit, high biological particle counts, low particle specific gravities and small size, a wide sediment gradation and high sediment specific gravity compared to biological particles all contribute to this challenge. Ballast water controls can be classified as illustrated in Figure 1.

Figure 1. Classification of ballast water management control strategies.

METHODOLOGY: Any unit operation (filtration, straining, flotation, coagulation and sedimentation) designed effectively for separation (or exchange) of biological particles, sediments or sediment-attached organisms requires an understanding of the physical and chemical characteristics of these particles and sediments. Parameters that are important from a treatment perspective include mass loading, particle gradation, particle diameter indices such as number mean volume size Lnv, specific gravity rs, specific surface area SSA, surface area SA, particle number NT, and particulate mass concentration M (as measured by gravimetric indices such as TSS). For example, Figure 2 illustrates such sediment characteristics that can be analyzed for use in a process selection diagram that evaluates the efficacy of unit operations for particle separation.

Figure 2. Example of sediment granulometry data for use in unit operation process selection.

RESULTS: Measurements such as those presented in Figure 2 can be input into a process selection diagram to select viable processes for particle separation. Figure 3 presents such a process methodology based on 90 percent removal efficiency (b) for particle counts and rs = 2.65. This methodology is developed as a management tool for control strategy selection in the paper.

Figure 3. Process diagram for selection of unit operations based on rs = 2.65 and b = 90 %.

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Author to contact:
J. Sansalone
Civil and Environmental Engineering
Louisiana State University
Baton Rouge, Louisiana 70803-6405
Ph: +225.578.6047
email: jsansal@lsu.edu

HUMAN INFLUENCES ON THE CONTAGION OF NON-INDIGENOUS MARINE FOULING SPECIES BY REACREATIONAL BOATING IN BOAT HARBORS

Oliver Floerl and Graeme J. Inglis

School of Tropical Environment Studies and Geography, James Cook University

Keywords: Marinas, recreational boating, post-invasion spread, recruitment, propagule pressure

The epidemiology of biotic invasions shares many common features with the spread of infectious disease (Mack et al. 2000). Epidemic Rapid spread of a non-indigenous species (NIS) is usually most favored when populations become established at vectors rapidly inoculate a number of widely separated populations locations and quickly attain a threshold size that allows them to become self-sustaining (Moody and Mack 1988), Factors which limit the rate of spread, therefore, include (1) the frequency with which new vectors are inoculated and travel to distant locations, and (2) the lag time involved in establishing viable breeding populations at each site. Human activities that affect recruitment success of the immigrant at local sites can, therefore, variously accelerate or impede its spread. Then large numbers of infectious propagules are produced at each focal site, and when between infected and potentially susceptible hosts are confined together in a restricted space. The spread of non-indigenous marine species (NIMS) by ocean-going vessels has many similarities with the epidemiology of human disease. In the latter, control of the spread of a communicable disease often focuses on the source of an outbreak where risk factors associated with exposure to the pathogen and its transmission are managed intensively. Transmission is most favored in situations where infected and potentially susceptible hosts are confined together within a small area. The spread of NIMS by hull-fouling also involves both individual and situational risk factors.

Despite centuries-long extensive research into the development of effective antifouling systems, hull fouling has continued to be a problem to the present day (e.g., Faubel & Gollasch 1996, Hay & Dodgshun 1997, Coutts 1999, Gollasch 1999; Floerl & Inglis, in review). In the light of the steadily increasing numbers of exotic species in biogeographic regions around the globe, there is currently a strong call to identify the overall potential of vessel fouling as an invasion and spreading pathway. It has been suggested that the capacity for the introduction or subsequent spread of exotic species is likely to be affected not only by characteristics of the transfer vectors in operation, but also by factors and processes prevalent in potential donor or recipient sites (Carlton 1996).

In marine environments, many non-indigenous species have characteristically disjunct distributions that are centered around sheltered harbors and ports. Given the rather disjunct distributions of many marine invasive species, and their frequent association with ports and harbours (Cranfield et al. 1998), it follows that studies aiming to assess the vector potential of hull fouling should incorporate both source/donor locations (i.e., ports and harbours) and the actual vectors (i.e., the vessels).

Recruitment Patterns of recruitment by marine invertebrates with planktonic pre-adult stages marine fouling organisms In marine populations recruitment strength are is strongly influenced by the abundance of competent dispersive propagules , local hydrographic conditions (Shanks et al. 1988; Roughgarden et al. 1991)and the availability of suitable adult habitat (e.g., Crisp & Ryland 1960; Meadows & Campbell 1972; McGuinness 1989; Anderson & Underwood 1994)., and external factors, two most important ones being (1) the physical and chemical nature of the prospective settlement surface (e.g., Crisp & Ryland 1960; Meadows & Campbell 1972; McGuinness 1989; Anderson & Underwood 1994), and (2) local hydrography (Shanks et al. 1988; Roughgarden et al. 1991). Hydrographic features, such as eddies and fronts, that concentrate and retain marine larvae in a limited area increase the supply of propagules to surrounding habitats and can enhance rates of local recruitment (Pingree & Maddock 1979, Wolanski & Hamner 1988, Geyer & Signell 1990, Signell & Geyer 1991, Archambault et al. 1998, Archambault & Bourget 1999).The same factors are likely to affect the magnitude of organism recruitment to vessel hulls. The toxic antifouling paints applied to the hulls of vessels' inhibit hulls interfere with (1), recruitment by either killing competent larvae, or by rendering the hulls an inappropriate making the surface unattractive settlement surface to competent larvae, or by killing settling larvae with the biocides emitted into the boundary layerfor settlement (Banfield 1980; Cristie & Dalley 1987). The design of port and harbour environments,

in contrast, might interfere with (2). Natural shoreline irregularities such as embayments or headlands have been shown to create complex oceanographic features such as eddies and fronts, that modify the dispersion of inert particles and marine larvae, and that can lead to localized and predictable aggregation of zooplankton and increased recruitment of larvae to adult habitats (Okubo 1973, Pingree & Maddock 1979, Wolanski & Hamner 1988, Geyer & Signell 1990, Kingsford 1990, Signell & Geyer 1991, Alldredge & Hamner 1980, Archambault et al. 1998, Archambault & Bourget 1999). Similar patterns of enhanced recruitment have also been observed in artificial embayments (e.g., McNeill et al. 1992).
Many non-indigenous marine species have characteristically disjunct distributions that are centered on sheltered harbors and ports. In these environments the risk of contagion is enhanced by the containment of large numbers of potential vectors (predominately ocean-going vessels) within a relatively confined space. Conditions that increase either the susceptibility of vessels to infection or the local abundance of infectious propagules will greatly increase the potential for spread.
In this paper, we present data on hull-fouling of recreational vessels to show how humans exacerbate both types of conditions. First, we examined how vector susceptibility was related to the frequency of vessel maintenance (antifouling) by determining the relationship between the last known date of antifouling and similarity between fouling biota on the hulls of the vessels and local source populations within the harbor. Second, we hypothesised that harbor designs could enhance recruitment of fouling species by entraining local water circulation. To test this, we compared rates of recruitment in two types of recreational boat harbors ("marinas") - those enclosed by a permanent breakwall, and unenclosed marinas - with recruitment in nearby coastal environments.

METHODS

In this paper, we investigate how humans can influence the contagion of exotic fouling organisms by on recreational vessels. Firstly, we ask how human-induced vessel selectivity can affect the risk of exporting species from a donor site. Secondly, we ask whether the enclosure of recreational boat harbours ("marinas") by permanent breakwalls leads to an entrainment of water within the marinas, and whether this entrainment enhances the propagule pressure to vessel hulls.

Between October and November 1999, we compared vessel fouling assemblages of on vessels in three Queensland (Australia) marinas and to the resident biota on the pilings and floating docks of these marinas were sampled using underwater photography. Percentage cover and composition of the assemblages was determined using photometric techniques and reference voucher specimens. Using iInterview data obtained from the vessel owners was used , we related to relate the vessel fouling patterns multivariate similarity of assemblages on the hulls and source marinas to the antifouling and travel behaviour of individual vessel owners.
In addition, we To determine the influence of harbor design on propagule pressure, we compared the rate of recruitment rates of fouling organisms to on clay experimental surfaces tiles in in multiple enclosed and unenclosed coastal marinas, as well as coastal control sites around the marinas and two coastal reference sites, in each of two regions (Cairns and Townsville). To test whether the enclosure of marinas by permanent breakwalls leads to an entrainment of water within the marinas, and whether recruitment patterns in all sites can be related The effects of harbor design on to the local flow regime, were examined we using subsurface drogues carried to determine out measurements of current patterns and velocities at each site using subsurface drogues.

RESULTS AND DISCUSSION

Our results show that with as the increasing age of the antifouling paints on vessel hulls increases, fouling the resemblance between hull fouling assemblages on the hulls converge to resemble those of the marina in which they are anchored (Fig. 1a)and marina resident assemblages progressively increases, i.e., . That is, resident vessels acquire subsets of from the local larval pool. Because of the overriding effects of antifoulant age on fouling patterns, the time the vessels had spent in the marinas could did not explain vessel-marina resemblance patterns reliably.
In enclosed marinas, rates Rates of recruitment of fouling species were between 1½ to 9 times greater in marinas enclosed by a breakwall than in unenclosed marinas,, and between 3 to 19 times greater than in adjacent coastal environments (Fig.1a1b).Patterns of the percentage cover of recruits on panels were similar to recruitment rates, with larger proportions of available panel space being colonized in enclosed than in

unenclosed marinas, and generally less biotic cover in control sites than in marinas. Differences in numbers of recruits and total biotic cover on panels between treatment locations differed between the two marinas. There were no differences in species richness between the various locations, indicating that marinas do not necessarily harbour more diverse fouling assemblages and larval pools than do adjacent hard-substratecoastal habitatsenvironments.

Our hHydrographic surveys in all marinas and control reference sites showed that the enclosure of coastal the marinas by solid breakwalls leads to caused much slower current velocities throughout the tidal cyclecompared to unenclosed marinas or control sites. Moreover, the wWater within the enclosed marinas appears to be entrained in an internal eddy system during periods of incoming tides, impeding or preventing the exchange of water with adjacent areas for a significant proportion of the day. In contrast, tidal current flow through exposed marinas and control locations is was always linear, ensuring continuous exchange of water with surrounding areas. It is likely that The entrainment of water in enclosed the marinas increases the number of concentrates and retains competent larvae available for colonizationwithin the harbor basin of space, while the lowered flow veloctities increase each propagule's chances for of contact with an available surface, and thus for successful settlement.

Our data indicate that vector selectivity and the design of recreational boat marinas design can, almost independent of one another, influence the potential of recreational vessels to facilitate the spread of exotic fouling organismsmay artificially amplify the rate of recruitment of fouling organisms and, thereby, allow them to develop self-sustaining populations more rapidly. The increase in propagule pressure within the harbor basin poses the greatest risk to boats that have not been antifouled within the past 12 months. The thoroughness with which the condition of the antifouling paint on the hulls of recreational vessels is monitored, and the rigorousness with which is it renewed once fouling begins to take place, strongly affect the potential of a vessel to transport species between locations. These two factors combined greatly increase the risk of contagion and spread of NIS.The design of marinas, with regard to their enclosure by breakwalls, can affect propagule pressure to recreational vessel hulls. The risk for species transfer is likely to be the cumulative product of both factors, and will thus be highest for vessels with very old antifouling paint that reside in enclosed marinas. The eEntrainment of water within these marinas might may also reduce the potential for spread of exotics NIS by advection, and help could to explain the often disjunct distribution of many established exoticsNIS, and their restriction to in widely separated port and harbour environments.

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Author to Contact:
Oliver Floerl
School of Tropical Environment Studies and Geography
James Cook University, Townsville, QLD 4811, Australia
Ph: +61-7-4781-6941
Fax: +61-7-4781 4020
Email: oliver.floerl@jcu.edu.au

HUMAN IMPACT AND MARINE BIOINVASIONS: SETTING GENETIC ANALYSIS OF THE JAPANESE DRILL, *OCINEBRELLUS* INORNATUS (RECLUZ, 1851), RECENTLY INTRODUCED INTO THE FRENCH ATLANTIC COASTS

Pascale Garcia-Meunier, Corine Martel, Jacques Pigeot, Guillemette Chevalier, Phillipe Goulletquer and Pierre-Guy Sauriau

Laboratoire de Bioligie et Environnement Marins (LEM), Université de la Rochelle

Key words: Ocinebrellus Inoratus, Marine Bioinvasions, Human Impact, Molecular Markers, French Atlantic Coast

Although they have existed for several centuries, biological invasions in marine environment accelerated considerably during the last decades mainly due to human-mediated dispersal mechanisms such as water ballast releases, ship fouling, and release of marine organism for mariculture purposes. Oyster and mussel industries in themselves, by movement of individuals (laying, spat, juveniles, adults) fixed on transported materials between shellfish production areas, represent without any doubt, the main cause for marine biological invasions (Carlton, 1992). The intentional release of species for aquaculture purpose is also known to be accompany by that indirect, of associated vegetal and animal species (Gruet & Baudet, 1997). These invasions cause potential ecological, economic and social risks (Goulletquer, 1998). The French shellfish farming is a good example of such process regarding to the new discovery of the mollusk gastropod *Ocinebrellus inornatus* (Récluz, 1851) in the Marennes-Oléron Bay (French Atlantic coast). This Japanese drill native to Asian Pacific coasts, was already introduced on the American West coast since 1924. On the French seashore, *Ocinebrellus inornatus* has been sampled for the first time in the oyster beds of Marennes-Oléron bay in 1995 (de Montaudouin & Sauriau, 2000) and since regularly observed (Pigeot et al., 2000). It cohabits with the native drill *Ocenebra erinacea* (Linné, 1758) which was until now, one of the main intertidal predator able to inflict real damage on cultivated oysters. This new invasion event lets predict an increase in the predation risk for cultivated species i.e. oysters and blue mussels, and for littoral fishing resources along French Atlantic coasts.

History of marine bioinvasions is often difficult to reconstruct because of the difficulty to determine precisely and without ambiguity, the period, location of first introduction and the speed of the expansion. Knowledge of life history of the nonindigenous species is also essential to the fundamental comprehension of the invasive phenomena and to the study of the consequences on the invaded ecosystems. However, and although the molecular and analytical tools of the genetics of the populations seem particularly adapted, in complement of the essential studies of taxonomy and ecology to answer this type of questions, one can deplore the lack of molecular data available at the present time (Boudouresque et al. 1994, Lee & Bell 1999, Ricciardi & MacIsaac 2000).

Three populations of *Ocinebrellus inornatus* in South Korea, Puget Sound (Washington, USA) and Fouras (French Atlantic coast), and one population of the native *Ocenebra erinacea* in the Marennes-Oléron bay were sampled. DNA extractions were carried out by the method of Chelex modified (Estoup et al, 1996). Thirty adults from each of the two species *Ocinebrellus inornatus* and *Ocenebra erinacea* were characterized genetically by random amplification of the genome, "Direct Amplification of Length Polymorphism (DALP)" (Desmarais et al, 1998). For each individual four fragments of mitochondrial DNA (12S, 16S, COI and Dloop) were amplified using universal primers, then sequenced and compared. Our main goal was to determine the genetic characteristics of the new species *Ocinebrellus inornatus* compared to those of the indigenous species *Ocenebra erinacea* .

We perform a DNA fingerprinting technique called DALP (Direct Amplification of Length Polymorphisms) to compare the two species *Ocenebra erinacea* and *Ocinebrellus inornatus*. This technique uses an arbitrarily primed PCR (AP-PCR) to produce genomic fingerprints and to enable sequencing of DNA polymorphisms in virtually any species.
We have observed distinctive fingerprints for both *Ocenebra erinacea* and *Ocinebrellus inornatus*, and intraspecific polymorphism in each species. The comparative profiles showed clearly 4 molecular markers

present only in the *Ocenebra erinacea* adults but missing in the *Ocinebrellus inornatus* adults tested, and 3 markers present only at *Ocinebrellus inornatus* adults.

So, we highlighted nuclear, specific markers of two species coexisting on the Atlantic coast, *Ocenebra erinacea* and *Ocinebrellus inornatus*. These markers enabled us to raise the doubt about the species of juveniles which identification is not sure according the only morphological criterias. Thus, in order to evaluate the ecological impact (diversity, abundance, distribution of the introduced drill , we will be able to perform accurate identification of juvenile stages and to analyze without ambiguity demographic profiles of non-indigenous populations.
Moreover, we proceeded to a comparison of fragments of mitochondrial DNA among the French, American and Korean populations of *Ocinebrellus inornatus* in order to recall the history of the invasion. Finally, our first results, already make it possible to consider the characterization of juveniles that are non identifiable on only morphological criterias and bring elements on the history of the invasion by *Ocinebrellus inornatus*.

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Author to contact: Pascale Garcia-Meunier
tél. :+33 (0)5 46 50 02 90,
E-mail : pgarciam@univ-lr.fr

THE GENETICS OF INVASION: A STUDY OF THE ASIAN VEINED RAPA WHELK, *RAPANA VENOSA*

Arminda L. Gensler, Roger Mann, and John E. Graves
School of Marine Science, Virginia Institute of Marine Science, College of William and Mary

Key Words: Rapana venosa, genetic variation, bioinvasion, DNA, cytochrome b

Molecular techniques have proven useful in assessments of patterns of invasion and colonization. Here, we use DNA sequencing of a 732 bp portion of the mitochondrial cytochrome b gene to investigate genetic relationships among native and introduced populations of *Rapana venosa*, a large predatory neogastropod. *Rapana venosa* is native to temperate Asian waters and has been to be a successful invader in the 20th century**.** *Rapana venosa* was introduced into the Black Sea in the late 1940s, probably through the unintentional transport of the bivalve predator in overland shipments of aquaculturally important Asian oysters. Since then, *R. venosa* has spread through European waters, and has become established in Uruguay (1999), and Chesapeake Bay, USA (1998). These latter introductions are believed to be mediated via ballast water transport of pelagic larvae. Larval propagules could be from single or multiple introductory events, and the source population could be either the native Asian populations or the colonial European populations.

As samples of both native and non-native populations are available for study, this work examines the relationship between genetic variability and colonization efficacy, and tests the hypothesis that colonial populations are less genetically diverse than the original parent population. Also, as we believe the newly discovered Chesapeake Bay population is the result of a relatively recent invasion, this study offers the opportunity to establish a genetic baseline, from which we can document changes in genetic variation over time.

Collections have been obtained from native (Korea, n=80) and non-native (Black Sea, n=40, and Chesapeake Bay, n=80) locations. A portion of the cytochrome b gene, generated through PCR amplification using primers designed by Collins et al (1996), will be sequenced. Haplotype frequencies and percent sequence divergence will be calculated. Estimates of genetic variation and genetic divergence within and among native and non-native populations will be assessed using phenetic and cladistic methods.

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Author to contact: Dr. Roger Mann
School of Marine Science
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062
Tel 804/684-7360
FAX 804/684-7045
e-mail: rmann@vims.edu

EXPERIMENTAL INFECTION OF NATIVE CALIFORNIA CRABS BY *SACCULINA CARCINI*, A POTENTIAL BIOCONTROL AGENT OF INTRODUCED EUROPEAN CRABS

Jeffrey H. R. Goddard

Marine Science Institute, University of California

Key Words: Biological control, *Carcinus maenas*, green crab, host-specificity testing, *Sacculina carcini*

The European green crab, *Carcinus maenas*, has invaded at least five regions on three continents, including the west coast of North America. Ecological and potential economic impacts of this hardy predator have prompted investigations into means of *controlling their populations. We tested in the laboratory the safety of using the rhizocephalan barnacle Sacculina* carcini, a parasitic castrator of green crabs in their native European range, as a potential biocontrol agent. For host specificity testing, we chose four species of native California crabs: *Hemigrapsus oregonensis*, *H. nudus* and *Pachygrapsus crassipes* based on their ecological overlap with green crabs in California, and the Dungeness crab, *Cancer magister*, for both its ecological overlap and economic importance. Using both non-preference and two-way preference trials, we exposed native and green crabs to infective female cyprid larvae of *S. carcini* and then counted the number of cyprids settled on each crab. We held crabs up to 22 weeks after cyprid settlement, dissected them, and then examined microscopically the digestive diverticula, intestine and thoracic ganglion for the internal roots of the parasite.

In preference tests using juvenile green crabs and *Cancer magister* or *H. oregonensis* of similar size, cyprid larvae of *S. carcini* settled in higher numbers on individual green crabs than on individuals of either native species. They also settled on a higher proportion of green crabs. In preference and non-preference settlement trials combined, 57 to 82% of the four native crabs settled on by *S. carcini* became infected by the parasite, compared to 64% of green crabs. Dungeness crabs suffered the highest infection rate. Eleven to 29% of the native crabs, but no green crabs, arrested early infections by melanizing and encapsulating the rootlets of the parasite. More than one third of the green crabs settled on by *S. carcini* did not develop infections or show a detectable host response (some even after settlement by high numbers of cyprids), compared to only 7 to 15% of the native California crabs.

For green crabs and all four native species combined, infection outcome was strongly dependent on the number of settled cyprids per crab and species of crab, but not hardness of the exoskeleton at time of exposure (logistic regression, whole model, $c2 = 44.55$, $P < 0.0001$, $R2 = 0.283$, $n = 96$). This result is reflected in the relationship between the percentage of crabs infected and the number of settled cyprids per crab shown in Figure 1. Settlement by three or fewer cyprids usually did not result in infection of green crabs, usually did in Cancer magister, and had intermediate results in H. oregonensis. At the highest settlement intensities, all native crabs, but not all green crabs, became infected. Using a least squares model to solve for both the per cyprid probability of infection and the proportion of crabs susceptible to infection, we estimated that 16% of green crabs were resistant to infection by S. carcini, compared to 6% and 3% of *H. oregonensis* and *Cancer magister*, respectively.

Infected green crabs survived longer than infected *Cancer magister*, but *S. carcini* had a large effect on the survivorship of both species. All infected *Cancer magister* were dead within 97 days of being settled on by *S. carcini*, compared to 65% of infected green crabs. In contrast, approximately 25% of the uninfected control crabs of both species had died during the same time period. Similar results were obtained for infected vs. uninfected *H. oregonensis*. No native California crab lived more than 154 days after infection by *S. carcini*, and we did not observe the external reproductive sac, or externa, of the barnacle in any of them. In contrast, infected green crabs lived up 355 days, and we observed externae in them as early as 142 days after cyprid settlement. In a few *Cancer magister* and *H. oregonensis* infected with *S. carcini* we observed that some or most of the nerve cords radiating from the thoracic ganglion were severely atrophied or missing entirely. Each of these crabs had been settled on by high numbers of cyprids. No such effect was observed in green crabs. Using a regression analysis, we found that survival of the infected native crabs, but not that of infected green crabs, was significantly related to settlement intensity. This suggests there is

little or no dosage-dependent effect of *S. carcini* roots on survival of its usual host, but that non-host species lacking previous association with the parasite are affected in a dosage-dependent manner. *Sacculina carcini* did not mature in the native California crabs and does not appear able to utilize them as alternate hosts. Nonetheless, its ability to infect and kill the native crabs in the laboratory suggest that S. carcini may not be sufficiently host specific for use as a biocontrol agent against green crabs on the west coast of North America. However, our results were obtained using unnaturally high larval densities. Further testing, using lower densities of S. carcini cyprids and larger exposure chambers with physical refuges for the crabs, is therefore needed to better assess the actual risks the barnacle might pose to native crab populations in the wild.

Although settlement by three or fewer cyprids usually did not produce infections in *H. oregonensis*, it usually did in *Cancer m*agister, suggesting that even low densities of S. carcini larvae might pose risks to juveniles of this commercially important species in the wild. Agency officials responsible for managing introduced green crab populations might have to weigh this potential risk of mortality to native crabs against the impacts of green crabs themselves on commercial shellfisheries and native ecosystems.

Author to Contact: Presenter and contact person:
Jeffrey H. R. Goddard
Marine Science Institute, University of California, Santa Barbara, CA 93106
(805) 893-8083
Fax: (805) 893-8062
Email: goddard@lifesci.ucsb.edu

ANTHROPOGENIC TRANSPORTS OF FOULING ORGANISMS AS A MEANS OF EXPOSING ISOLATED MARINE ENVIRONMENTS TO NONINDIGENOUS SPECIES: A CASE STUDY IN HAWAII

L. Scott Godwin

B. P. Bishop Museum

Key Words: Nonindigenous species, anthropogenic dispersal, fouling

The native species of the marine and terrestrial environments of Hawaii arrived as natural biological invasions through historical time, and through evolution and adaptation became the present communities associated with the archipelago. The islands of Hawaii are one of the most isolated areas in the world and all native plants and animals exist due to the pioneering species that settled here originally. The advent of modern history has created new human - mediated, or anthropogenic, biological invasions through non-natural mechanisms. In terms of natural dispersal mechanisms, species invasions to new regions are rare in time scales measured from the human perspective because of the barriers that must be overcome. In Hawaii's marine environment, examples of these natural barriers are ocean currents and distance from continental land masses. It is theorized that marine species that colonized Hawaii before the presence of the first Polynesians arrived on flotsam such as logs and pumice stones. These natural species invasion events are rare and measured on the scale of geological time. The natural barriers that exist in isolated marine environments such as Hawaii are overcome by anthropogenic influences on dispersal patterns. This creates a situation where the isolated marine environments of the Hawaiian Archipelago are more readily exposed to nonindigenous species. A case study of two anthropogenic dispersal modes: maritime vessel hull fouling and derelict commercial fishing gear are reviewed. These modes combine to have effects on altered habitats such as Honolulu Harbor and Pearl Harbor, and pristine marine reserve habitats such the Northwestern Hawaiian Islands.

Author to Contact: L. Scott Godwin
Bishop Museum
Natural Sciences
1525 Bernice St.
Honolulu, HI 96817-2704
808-8484-4156 (Phone)
808-847-8252 (Fax))
Email: sgodwin@mail.bishopmuseum.org

EVALUATION OF THE EFFECTIVENESS OF THE AQUAHABISTATTM SYSTEM FOR TREATMENT OF BALLAST WATER

Andrew S. Gordon and Dale Horeth

Department of Biological Sciences, Old Dominion University

The AquaHabistatTM (AHS) treatment system for ballast water utilizes the principle of dissolved oxygen removal to kill organisms in ballast tanks. We were contracted by Browning Transport Management, Inc. to evaluate the effectiveness of the AHS system in a mesoscale prototype. The prototype consisted of a deoxygenation tank that utilized vacuum for initial dissolved oxygen (DO) removal. The AHS prototype was installed in a facility adjacent to the Elizabeth River, Virginia near the Lambert's Point Docks. Water was drawn into 20,000 liter (ca. 5300 gal or 22 ton) pools inside the facility at a rate of 72 tons per hour. Details of system operation can be found at www. wjbrowning.com /browning.asp.

Tests to evaluate the effectiveness of the treatment system utilized two pools. One pool received treated water and one received untreated water and was utilized as a control. After filling, the pools were covered with black plastic sheeting to simulate conditions in a ballast tank. In some experiments a nitrogen stream was utilized to maintain low DO in the pool containing treated water. DO, temperature, pH and salinity were monitored in each pool. Biological effects of the treatment were followed for ten days.

Biological effects were monitored by microscopic counts of copepods, zooplankton other than copepods (in aggregate) and by ATP measurement. Zooplankton were collected by plankton net tows (80 mM mesh) in the pools. Zooplankton were enumerated microscopically. ATP was determined by extraction of material retained on filter paper with either 10 or 20 mM pore size. ATP concentrations were measured by the luciferin/luciferase luminescence assay. In preliminary experiments bacterial numbers were determined by the spread plate method and by direct counts using epifluorescence microscopy. Experiments, each utilizing one control and one experimental pool, were repeated in triplicate. In each experiment replicate tows and ATP extractions were performed at each sampling interval.

Initial dissolved oxygen concentration in Elizabeth River water was reduced from ca. 8 p.p.m. to 1 p.p.m. by the treatment. All biological indicators with the exception of bacteria showed similar trends. Bacterial numbers were not reduced by the treatment. Zooplankton and ATP concentrations showed a 50 to 75% decrease at the initial sampling time (day 0). After day 0 living zooplankton and ATP decreased both in the control and treated tanks. The rate of decrease in organisms and ATP was consistently faster in the treated pool. Final reduction of biomass in the treated pool based on ATP measurement after ten days ranged from 73 to 100%. Live zooplankton (>80 mM) were not observed after two days in the treated pool. In the control pool live zooplankton and measurable ATP were observed throughout the study period. Significant reduction in biomass was also observed in the control pool however.

In summary, removal of oxygen from Elizabeth River water with the AHS system accelerated the death rate of zooplankton greater than 80 mM in size and the rate of loss of biomass as measured by ATP in the greater than 10 mM size fraction under simulated ballast tank conditions. ATP in this size fraction would have been derived from phytoplankton and zooplankton but not free-living picoplankton or bacterioplankton. Since the death rate of organisms is accelerated by removal of DO, these experiments indicate that treatment of ballast water by DO removal will reduce the likelihood of potentially invasive hitchhikers surviving transit in ballast water. The next step required for testing of the AHS system is scale up to sea-going vessels.

Author to Contact: Andrew S. Gordon
Department of Biological Sciences, Old Dominion University
Norfolk, VA 23529
Tel 757-683-3595
FAX 757-683-5283
Email: Agordon@odu.edu

ECOLOGICAL AND ECONOMIC IMPLICATIONS OF THE TROPICAL JELLYFISH, *PHYLLORIZA* PUNCTATA, IN THE NORTHERN GULF OF MEXICO DURING THE SUMMER OF 2000

William M. Graham, Dauphin Island Sea Lab, Alabama
Harriet M. Perry, Gulf Coast Research Lab, Mississippi
Darryl L. Felder, University of Louisiana, Lafayette, Louisiana

Key Words: medusae, Loop current, fisheries

A large population of a previously unreported jellyfish occurred across the northern Gulf of Mexico from May through September of 2000. The population of jellyfish, identified as *Phyllorhiza punctata* von Lendenfeld, is not indigenous to the Gulf of Mexico, or even to the Atlantic Basin. A current hypothesis suggests that *P. punctata*, a rhizostomous scyphozoan in the Family Mastigiidae, was introduced into the Atlantic Basin from the Pacific Ocean at least 45 years ago. While the summer 2000 was the first documented occurrence of the species, it is likely that *P. punctata* has been in the Gulf for at least several years as 'cryptic' populations. *P. punctata* is native to the tropical western Pacific Ocean, but has been successful in migrating around the world including Hawaii, southern California, the eastern Mediterranean and the Caribbean Sea and the Gulf of Mexico.

The Gulf of Mexico population of *Phyllorhiza punctata* was first observed about 20 km south of the Alabama coast in May, 2000. During July and August there was a marked westward propagation of the population, and by early August the population extended from Mobile Bay, Alabama to the mouth of Lake Borgne, Louisiana. Within this overall distribution, highly concentrated aggregations of medusae were observed within the passes of the barrier island chain. There were also high concentrations of medusae along the northern shores of these barrier islands. Yet, the most striking concentration by mid-August was at the mouth of Lake Borgne, Louisiana where it is estimated an area of approximately 150 km2 contained 6 x106 medusae (based on aerial survey estimations). Within this larger aggregation were localized concentrations on the order of 0.5 ind m-2 in water < 4 m deep. The overall westward drift of the population was not unexpected since this is the direction of the coastal current of the northern Gulf of Mexico. A rapid decline in extent of the population and in the concentration of medusae has occurred by early October. Advection of the population back into the Gulf of Mexico may have occurred, but it appears that a large portion of the population has either senesced or succumbed to several intense cold-front passages.

Several important differences between the Gulf population of *Phyllorhiza punctata* and other populations throughout the world, including the closest northern Caribbean populations of Puerto Rico. The two most obvious differences are pigmentation and size. All other populations *P. punctata* are very deep brown owing to the presence of zooxanthellae (algal symbionts). However, the Gulf population does not host zooxanthellae. The lack of zooxanthellae in the Gulf population may be due to extensive bleaching, caused perhaps by stresses encountered during a northward movement into cooler, lower salinity waters. Alternatively an established cryptic population of *P. punctata* may have lost zooxanthellae perhaps because energetic requirements are met from zooplanktivory. Loss of zooxanthellae as an energy source is particularly intriguing since energetic requirements must be met by zooplanktivory, which reflects a curious size difference between Gulf *P. punctata* and other populations. Without zooxanthellae, *P. punctata* in the Gulf of Mexico ranged in size from 35 cm diameter to over 65 cm. A 65 cm individual has a wet mass of about 20 kg (96% water). With zooxanthellae, medusae in the Caribbean and Australia are capable of exceeding daily energetic needs using photosynthetic product only. Even with this energetic supplement, reported maximum sizes of individuals are 35 cm in the Caribbean and 30-40 cm in the Pacific. Because this species - as well as nearly all medusa populations - are food-limited, the large size of the Gulf of Mexico individuals suggests that high energetic needs are being met from grazing on the regionally very high secondary production rates.

The potential for negative impacts is very real in terms of both ecology and economics. On an economic level, the most concentrate aggregations in July and August coincided spatially and temporally with shrimping activities in the Mississippi Sound. Also, jellyfish are quite notorious consumers of fish eggs and larval fish. Both fish eggs and dominant copepods (primarily *Acartia tonsa*) were being cleared at a rate of

nearly 100% per day. In fact, estimated clearance rates were on the order of 50 m3 ind-1 d-1, which suggests that, at their most concentrated, these medusae were turning over the water about 5 times each day. Fortunately the areal extent of the aggregations in 2000 were limited to a relatively small region of the northern Gulf of Mexico. However, the main concern is that this 'already proven' invader will establish regional populations and that future populations will increase in size due to availability of food resources. Precisely how *Phyllorhiza punctata* has been translocated around the world is very confusing. Adding to the difficulty of understanding translocation of populations is the taxonomic confusion that surrounds the entire Phylum Cnidaria, much less difficulties found within the Family Mastigiidae. The taxonomy issue is not avoided as we try to understand how and when this invader was introduced into the Gulf of Mexico. However, it will require a much larger effort involving molecular systematics to discriminate population, species, genus and family-level variations and connectivity to resolve these issues.

Author to Contact: William (Monty) Graham
Dauphin Island Sea Lab
101 Bienville Blvd.
Dauphin Island, Alabama, 36528
phone: 334-861-7555
fax:334-861-7540
Email: mgraham@disl.org

MORPHOLOGICAL VARIATION BETWEEN THREE POPULATIONS OF THE VEINED RAPA WHELK, *RAPANA* VENOSA, A RECENT GASTROPOD INVADER OF THE CHESAPEAKE BAY

Rebecca Green, Roger Mann, and Juliana M. Harding, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA

Key Words: *Rapana venosa*, Veined rapa whelk, Chesapeake Bay, gastropod, morphometrics

The gastropod form, such as that of *Rapana venosa*, is restricted by its unique molluscan phylogeny, yet gastropods show remarkable diversity both on the interspecific and intraspecific levels. Since the phenotypic traits of the gastropod shell are under genetic and environmental controls, bioinvasions yield an opportunity to investigate the impact of novel environments on a single species. The initial introduction of *R. venosa* from the Bohai Sea, Yellow Sea, and Sea of Japan system of Northern Asia to the Black Sea and Mediterranean Sea systems of Europe occurred during the 1940s. Subsequently, *R. venosa* was introduced from presumably the European population to the Chesapeake Bay, Virginia, U.S.A. in the 1990s. This invasion allows for the comparison of three populations of whelks in environments that differ in their present day and historical ecologies. For this study, *R. ve*nosa were collected from the Yellow Sea, Korean Straits, Black Sea, and Chesapeake Bay, U.S.A. Additional specimens were obtained from the historical collection within the Smithsonian Institute's Museum of Natural History. Using computer based image analysis, characteristic measurements were made. These measurements were then compared using both multivariate and bivariate methods. The majority of the variance was due to size and allometric differences. The observed shell form variation in *Rapana venosa* most likely results from ecological as opposed to genetic controls. This study examines potential ecological causes and impacts to shell form between the Yellow Sea, Korean Straits, Black Sea, and Chesapeake Bay populations of the invasive gastropod, *Rapana venosa*.

Author to contact: Dr. Roger Mann
School of Marine Science
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062
Tel 804/684-7360
FAX 804/684-7045
e-mail: rmann@vims.edu.

History of Nonindigenous Aquatic Invertebrate Introductions in the Black, Azov and Caspian Sea Basins

Igor A. Grigorovich and Hugh J. MacIsaac

Key Words: biological invasions, intentional stocking, ship vectors, Black-Azov-Caspian basins

The Black, Azov and Caspian sea drainages (i.e. Ponto-Caspian region) have an extensive and long-standing history of nonindigenous species (NIS) introductions. We review patterns and mechanisms of invertebrate NIS introductions into these ecosystems. Since the late 1800s, more than 143 nonindigenous invertebrate species have been introduced outside their native ranges and have become established in the Ponto-Caspian region. The bulk of these introductions were by crustaceans (57%), molluscs (14%) and annelids (11%). Most of the introduced NIS are native to other areas within the Ponto-Caspian region (43%), with other sizable contributions from the Atlantic-Mediterranean region (12%) and from northern-central Eurasia (11%). Mechanisms of introduction were dominated by deliberate releases (33%) and shipping activities (18%), with the former occurring principally in freshwater habitats and the latter in marine and estuarine ones. Many (19%) other introductions resulted from interacting vectors, particularly construction of canals and shipping activities. Expanding global trade provides enhanced dispersal opportunities for nonindigenous invertebrates, indicating that future invasions by nonindigenous invertebrates may be expected to continue. The invasion history of the Ponto-Caspian region is consistent with the emerging concept that implicates the frequency and intensity of propagule transfer (i.e. propagule pressure) to new geographic regions as a primary determinant of invasion success.

Author to contact: Dr. I. Grigorovich
gigoruw@uwindsor.ca
ph. (519) 253-3000 ext. 2734
fax (519) 971-3616

DO CHANGES IN BODY SIZE ACCOMPANY INVASIONS OF INTRIODUCED MARINE AND ESTUARINE SPECIES?

Edwin Grosholz, University of California

Davis and Gregory Ruiz, Smithsonian Environmental Research Center

Key Words: Invasion success, body size, size change, introduced range, predators

One of the key questions for invasion biologists is what features may allow introduced species to be successful in the newly invaded range. Changes in the body size of invaders in the invade range relative to the new range may strongly affect their ecological performance. For species like the introduced European green crab and other predatory crustaceans, increased body size may affect access to shelled prey, interactions with other guild members, and reproductive output. Our recent work has shown that many populations of the green crab and other marine and estuarine invaders show significant increases in body size in the introduced range relative to the native range. Using both recent field collections as well as literature-based estimates, we found that for several invaders, body size is significantly larger in the introduced range relative to the native range, while other invaders remain unchanged in the new range. The factors that may be responsible for increased body size in the introduced range are discussed.

Author to Contact: Edwin Grosholz
Department of Environmental Science and Policy
University of California, Davis, CA 95616
phone (530) 752-9151
FAX (530) 752-3350
email: tedgrosholz@ucdavis.edu

REDUCING THE RISK OF IMPORTATION AND DISTRIBUTION OF NONINDIGENOUS SPECIES THROUGH OUTREACH AND EDUCATION

Edwin Grosholz, University of California
Davis and Gregory Ruiz, Smithsonian Environmental Research Center

Key Words: Non-ballast, vectors, prevention, risk, importation

The scope of the invasive species problem in the San Francisco Bay-Delta region has resulted in direct action by a consortium of state and federal agencies known as CALFED to develop a Strategic Plan for Non-native Invasive Species. This plan makes prevention of future introductions of invasive marine and estuarine species one of their top priorities. Their strategy centers around the realization that the most effective strategy, either from the point of view of minimizing costs or maximizing ecosystem health, is to prevent introduced species from becoming established in the first place. This goal -- preventing future introductions -- is the main objective of the RIDNIS project. The objectives of the RIDNIS project include facilitating communication among industry, agencies and academia about the problems posed by NIS in the San Francisco Bay/Delta and the future risks associated with the continued importation, sales, and distribution of live exotic species. Our efforts include targeting industries such as the aquarium and pet trades, landscape contractors, nursery and aquatic plant dealers, "aquascape" contractors, seafood importers, bait dealers, and associated industries. By increasing communication between industry, agency and academia, the RIDNIS project attempts to develop new ways of minimizing the risks of both unintentional and intentional release of NIS. This objective is being realized through various approaches including targeted workshops aimed designed for different industry, agency and academic groups, distribution of brochures with relevant information, video presentations, and a NIS non-ballast vector website (http://www.ridnis.ucdavis.edu).

Author to Contact: Edwin Grosholz
Department of Environmental Science and Policy
University of California, Davis, CA 95616
phone (530) 752-9151
FAX (530) 752-3350
email: tedgrosholz@ucdavis.edu

LOCAL LEGAL SOLUTIONS TO A GLOBAL PROBLEM: HOW HAWAI'I HOPES TO PROTECT ITS ISOLATED PORTS FROM MARINE BIOINVASIONS

Heidi Kai Guth

William S. Richardson School of Law, University of Hawaii

Keywords: Hawai`i, ballast water, nuisance species, bioinvasions

The Hawaiian Islands are the most isolated archipelago in the world, with the closest large landmass (North America) more than 4,300 km away. Such insular ecosystems are often highly susceptible to change. Hawai`i, therefore, must be at least as vigilant as any other international port region in preventing the introduction of aquatic nuisance species. Its isolation makes it a prime testing ground for strict local regulations, because losing business to other ports due to ships avoiding Hawai`i's port regulations is far less likely, and, with fee-generating regulations, the relatively few Hawaiian ports could be monitored. Because existing international and national guidelines are mainly reactionary to specific, isolated events, or are voluntary, one approach is to make a local state responsible for the protection of its ports via a precautionary approach (defined by Article 15 of the 1992 Rio Declaration as meaning where "there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."). While international customary law and national practice seem to reinforce the view that coastal areas may exclude foreign vessels from entering their ports, the reciprocal interest in using each other's ports often makes that difficult. Despite this protocol some states have begun to deny access to vessels, due to oil spill management, which could endanger the physical and environmental safety of the port. Similar modified access could include concerns about ballast water.

Shipping lines must pay additional port fees of $600 per visit to fund research. According to the National Ballast Water Clearinghouse's first annual report on the national reporting of ships' ballast water management, the highest level of compliance was among vessels entering California's ports. However, the report showed no corresponding increased compliance in ballast exchange. In July 2002, Washington State plans to expand its present regulations and be the first state to require that vessels treat all water that has not been exchanged on the high seas. The initial penalties will be up to $500 each time a report is not filed, and up to $5,000 for dumping violations. Hawai`i could add to the solidarity of Western American ports' regional resistance to marine bioinvasions. The 2000 Hawai`i Legislative session assigned a lead agency to alien aquatic organism prevention. The agency must solicit federal funds, and without those funds, it cannot meet the mandate. According to Barber v. Hawai`i 42 F.3d 1185 (9th Cir. 1994), the State of Hawai`i has the right to "enact legislation and adopt rules regulating anchorage and mooring privileges within its ocean waters and navigable streams." The Ninth Circuit found that such legislation did not violate UNCLOS, because the treaty says, "foreign ships exercising the right of innocent passage shall comply with the laws and regulations enacted by the coastal State, in particular with such laws relating to transport and navigation." There was no conflict with the U.S. Commerce Clause because the mooring restriction had no more than incidental effects on interstate commerce, and in balance, the local benefits were great. The Ninth Circuit also found the local legislation did not preempt federal legislation because there was no direct conflict, the Coast Guard saw no such conflict, and the court could not create a hypothetical conflict. All of the above tests, if pre-applied to state legislation mandating ballast water exchange should permit the promulgation of a strong state law. Only by local ports requiring mandatory ballast water exchange, or its effective equivalent, and by being strict with their legislation and implementation, will other states and nations begin to have to meet standards with their flag ships, and, through required acquiescence, form a new internationally accepted expectation of cooperation and global regulation.

Author to contact: Heidi Kai Guth
William S. Richardson School of Law, University of Hawaii
509 University Ave. #507
Honolulu, HI 96826
808-941-4059
Email: heidikai@worldnet.att.net

CHANGES IN DECOMPOSITION AND ALTERATION OF MICROBIAL COMMUNITY COMPOSITION CAUSED BY AN INVASIVE INTERTIDAL EELGRASS, *ZOSTERA* JAPONICA, IN A WASHINGTON ESTUARY

Daniel R. Hahn - University of Washington, Dept. of Zoology

Key Words: decomposition, microbial functional diversity, eelgrass

Biological invasions clearly alter the composition and community dynamics of invaded areas and can potentially alter ecosystem processes including productivity, decomposition, nutrient cycling and hydrology (Vitousek 1990). Quantitative data demonstrating such effects, however, are scarce, especially in marine environments (Ruiz et al. 1999). I conducted research in Padilla Bay, Washington to examine the effects that an introduced intertidal eelgrass, *Zostera jap*onica, has on microbial processes, rates of decomposition, and associated community and ecosystem properties in this estuarine environment. Presented here are the results of a combination of observational and experimental studies that examined sole source carbon usage (SSCU) by microbial assemblages, enumerated bacterial abundance, and measured rates of decomposition of native and invasive eelgrass in beds of *Z. japonica* and in beds of its native congener, *Z. marina*.

About 100 years ago, *Z. japonica* was accidentally introduced to Washington State with shipments of oysters from Japan (Harrison and Bigley 1982). It has since spread along the coastline, replacing mudflat habitat (Posey 1988) and overlapping extensively with the native eelgrass, *Z. marina*. *Zostera japonica* tends to be higher in the intertidal than its native congener and thus, in any comparisons between native and invasive eelgrass, tidal height is a confounding factor. In order to separate the effects of tidal height from vegetation effects, I transplanted small beds of native, invasive, and mixed eelgrass to several heights within the intertidal. Decomposition bags were then placed in these transplanted beds as well as in the naturally occurring beds. Soil cores and microbial samples were collected from these beds as well.

Microbial assemblages isolated from transplanted beds of native and invasive eelgrass showed different patterns of carbon source use. However, patterns of SSCU did not differ when compared among different tidal heights. In contrast, no difference in total microbial abundance was detected among tidal heights or among vegetation types. The similarity in bacterial abundance combined with differences in SSCU indicates that microbial assemblages differ in composition, rather than number, between beds of the invasive and native species. Decomposition of eelgrass in the field differed between *Z. japonica* and *Z. marina*, though the rate of decomposition was variable between years. In general, the invasive species decomposed at a more rapid rate than the native.

The results of this study indicate that this abundant invasive species has the potential to alter ecosystem level processes such as decomposition and nutrient cycling. The rapid decomposition of the invasive eelgrass could lead to more rapid nutrient cycling which could in turn feed back into higher levels of productivity. Results also suggest that *Z. japonica* alters the associative decomposer assemblage and the functional diversity of microbes where it is present, which may further lead to alterations in decomposition, nutrient cycling, and nutrient retention.

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Author to contact: Daniel R. Hahn
University of Washington
Box 351800
Seattle, WA 98195-1800
Phone: (206) 523-9991
Fax: (206) 543-3041
Email: hahnd@u.washington.edu

GROWTH RATES OF LARVAL AND JUVENILE VEINED RAPA WHELKS *RAPANA* VENOSA FROM CHESAPEAKE BAY, U.S.A. FROM HATCH THROUGH AGE 1

Juliana M. Harding and Roger Mann, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA.

Key Words: Veined rapa whelk, *Rapana venosa*, oyster, hard clam, generalist predator

The apparent success of the introduced veined rapa whelk, *Rapana venosa* , in the lower Chesapeake Bay, USA is facilitated by general habitat and food requirements resulting in rapid growth rates of larval and juvenile snails. Rapa whelk veliger larvae display considerable variation in time from hatch to settlement although they are morphologically competent to settle after 21 days. Veligers grow quickly on mixed algal diets reaching shell lengths in excess of 0.5 mm at 21 days. Rapa whelk veligers display little substrate specificity at settlement and settle successfully on a wide range of locally available attached macrofauna including bryozoans and barnacles. Once settled onto hard substrates, young rapa whelks are generalist predators and consume large numbers of barnacles, mussels, oyster spat, and small oysters. Recently settled rapa whelks grow at > 1 mm per week reaching shell lengths of 40-50 mm within 5 months post-settlement and > 60 mm SL at Age 1. These extremely fast growth rates combined with the rapa whelk's cryptic coloration, nocturnal habits, and preference for oysters as both food and habitat offer serious cause for concern particularly in light of ongoing oyster restoration efforts in the lower Chesapeake. Evidence suggests that rapa whelks occupy shallow hard substrate habitats until reaching shell lengths in excess of 70 mm and then migrate into deeper habitats with sand or mud substrates where they forage on infaunal bivalves including soft clams (*Mya* sp.) and hard clams (*Mercenaria mercenaria*).

Author to Contact: Dr. Roger Mann
School of Marine Science
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062
Tel 804/684-7360
FAX 804/684-7045
e-mail: rmann@vims.edu.

DISTRIBUTION OF AN INVASIVE ANOMURAN DECAPOD, *PETROLISTHES* ARMATUS, IN THE NORTH INLET – WINYAH BAY NATIONAL ESTUARINE RESEARCH RESERVE (NERR) IN THE SOUTH CAROLINA COAST

M. J. Hartman and S. E. Stancyk

Marine Science Program and Belle W. Baruch Marine Institute, University of South Carolina

Key Words: benthic ecology, biodiversity, crustaceans, decapod, South Carolina

Petrolisthes armatus is a filter-feeding crab which appears to be extending its range northward along the southeast coast of the United States. *P. armatus* is native to Brazil and has been reported from Florida, Mississippi, Georgia and Charleston, South Carolina. Recently, *P. armatus* was found in the North Inlet-Winyah Bay National Estuarine Research Reserve (NERR) 60 miles north of Charleston and has been detected in Murrells Inlet, 20 miles further north, within the last few months. This is preliminary information from an ongoing project to study the distribution and biology of P. armatus in the North Inlet - Winyah Bay NERR. Sampling of *P. armatus* is conducted by randomly placing 0.135 m2 trays filled with oyster rubble in subtidal and lower intertidal zones at three sites in North Inlet. Trays are collected after one month and all *P. armatus* individuals are counted. Samples from July - November 2000 yielded an average *P. armatus* density of 47.4/ m2 individuals in the subtidal trays (range: 0 - 303.7/m2) and 98.5/m2 individuals in the intertidal trays (range: 0 - 503.7/m2). Sex ratios were male-biased, 1.5:1 for both subtidal and intertidal trays. Future studies in the laboratory and field will examine substrate preference, movement of *P. armatus* over tidal cycles and behavioral interactions between xanthid crabs and P. armatus.

Author to contact: M. J. Hartman
Marine Science Program
University of South Carolina
Columbia, S.C. 29208
phone # (803) 777-3508
fax # (803) 777-3935
Email: maryjo@sc.edu

top

EFFECTS ON THE MICROBIAL COMMUNITY FROM BALLAST WATER DISCHARGE AT THE NORWEGIAN WEST COAST

Hess-Nilsen, Ole Kristian(1), Jelmert, Anders(2) and Enger, Øivind(1) 1) Institute of Microbiology, P.O. Box 7800, Jahnebakken 5, N-5020 Bergen, Norway
2) Institute of Marine Research, Austevoll Aquaculture Research Station, N.5392 Storebø, Norway

Key Words: Ballast, bacteria, virus, DNA, diversity

Transport of ballast water with ships represent a potential risk for introduction of foreign species (1, 2), and could thereby alter the flora and fauna of the recipient water. We have studied ship-mediated transfer of microorganisms from foreign ports into the waters around Bergen at the western coast of Norway, where two of the largest oil refineries in Norway are situated. The region receives approximately 30 million ton of ballast water annually.
This area is also Norway's most productive aquaculture region, with close to 1/4 of the total Norwegian fish farming production (3). We collected samples from the vessel ballast and the port of call water before and after the discharge of ballast water. By comparing the bacterial diversity in these samples, it is possible to find an indication on how the ballast water affects the microbial flora at the vessel port of call (4).
We investigated the microbial community by using traditional microbial methods combined with total counts of bacteria and viruses and by molecular methods. Colony forming units (cfu) were determined with and without addition of different antibiotics to the media. The cfu without antibiotics varied within a range of 1,6 x 102 - 2,6 x 103 cfu/ml, which is within the normal range for coastal waters in temperate regions. The number of cfu showed no obvious negative correlation to the length of the journey.
Bacteria growing in the presence of Oxytetracycline were encountered in both ballast water and in recipient samples. Typically they were found at higher numbers in the ballast water compared to the recipients. We did not try to clarify if this resistance was of anthropogenic or natural origin. In the ballast water, gram negative bacteria growing in the presence of Flumequine, Streptomycin and Oxytetracycline antibiotic susceptibility discs were found. Such bacteria were also found in the recipient, but at lower numbers. Total counts of bacteria and viruses were determined by epifluorescence microscopy.) The total number of bacteria and viruses in one of the samples were especially high, 1.7 x107 /ml and 3.1 x 108 / ml, respectively. This ballast water had strong signs of a local algal bloom in the ballasting harbour. On the other vessel examined, the population numbers were more normal, 7.7 x105 /ml and 1.9 x 107 /ml, respectively, which corresponds to the numbers found in the recipient waters.
Total-DNA was extracted from the water samples and amplified by PCR prior to diversity assess ment by DGGE separasjon (5-8). This resulted in a profile with 7-8 dominant bands and several unique bands. Most reamplified and sequenced to find the bacteria's taxonomic afiliation. By comparing our sequences with already known sequences (9, 10) we found mainly organisms related to unidentified alpha-proteobacteria and unidentified species of the order Cytophagales. The ballast water samples were also examined by specific V. cholera primers for the bacterial strains Vibrio cholera O1 and O139, which causes human epidemic cholera. In the two vessels examined no V. cholera was detected.

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Author to Contact: Jelmert, A.,
Institute of Marine Research
Austevoll Aquaculture Research Station
N-5392 Storebø, Norway.

MARINE BIOINVASIONS: VICTORIA'S TARGET-SPECIES, RISK-BASED APPROACH

Don Hough[1] and Sarah Walters[2]

[1]Department of Natural Resources and Environment - Victoria, Australia
[2] Environment Protection Authority - Victoria, Australia

Key Words: risk, target species, management

Victoria is one of Australia's seven States and Territories with ocean boundaries. It lies in southeastern Australia at 39° S and its 2000 km coastline forms the northern boundary of a broad strait that attains a maximum depth of 80 m. Near-shore waters vary from estuarine to oceanic and have annual temperature ranges from about 13° to 22° C. Victoria is home to four international trading ports that host 3,900 vessel arrivals per year. The four ports are either privately-owned and operated or Government-owned through a corporation with a mix of private operators. Some 10 small Government-owned ports service the local and regional needs of commercial and recreational fishing sectors and the offshore petroleum industry. Marine aquaculture is currently limited.

Opportunities for the human introduction of exotic marine species to Victoria arose in the 1850s when international vessel arrivals became routine. The first introduced marine species was reported in 1862. There are 165 exotic or cryptogenic marine species known to be introduced in Victoria. Although a range of vectors are implicated in these introductions, since the 1990s ballast water has become the dominant source of introductions. The rate of new introductions is estimated to be 2-3 species a year.

Australian efforts to deal with marine introductions commenced in the 1970s and accelerated in the early 1990s. Concern about the slow pace and the lack of a practical, co-ordinated response to reduce introductions lead the Victorian Parliament, in 1995, to commission an Inquiry into ballast water and hull fouling. In 1998 the Victorian Government accepted the Inquiry's 15 high-level recommendations. These focused on establishing an effective State-based legislative and administrative framework that deals with marine introductions. Following the 1999 *Mytilopsis* sp outbreak in northern Australia - a potential national disaster for both the natural environment and all marine-based industries -Victoria accelerated the implementation of co-ordinated arrangements appropriate for a federal system of Government.

Victoria has adopted a target-species based approach to assessing and managing risk that takes into account the economic, environmental and social impacts of specific species (target species). Similar arrangements are being developed by the federal Government. The approach is used in preventing primary and secondary introductions, triggering emergency responses to new introductions, and mitigating impacts of established introduced species.

The promotion and application of this approach has highlighted differences in opinion on the theory and the implementation of the approach between various stakeholder groups. These differences appear to reflect the outcomes desired by the various groups.

The paper will discuss Victoria's experience and progress in the practical implementation of a target-species based approach to risk management; it will highlight lessons learnt to date and their potential relevance to public and private sector managers dealing with marine invasions. Discussion will consider the influence of Australia's federal system of government, approaches to biosecurity generally, and the perspectives of different stakeholders with an interest in the marine environment.

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Author to Contact: Don Hough
Department of Natural Resources and Environment
GPO Box 500
East Melbourne, 3002, Victoria, Australia.
T (+61) 3 9637 8443
F (+61) 3 9637 8117
Email Don.Hough@nre.vic.gov.au

OPTICAL SIGNATURES OF SEA WATER AND THEIR POTENTIAL USE IN VERIFICATION OF AT SEA BALLAST WATER EXCHANGE

Carlton D. Hunt[1], Deborah Tanis[1], Elizabeth Bruce[1], Bob Chen[2], Steve Rudnick[2] and Michael Taylor[3]
[1] Battelle, 397 Washington Street, Duxbury,. MA
[2] University of Massachusetts, Boston, MA
[3] Cawthron Institute, Private Bag 2,Nelson, New Zealand

Voluntary guidelines for open ocean ballast water exchange have been imposed on vessels entering US ports from foreign ports to help control the invasion of non-indigenous species (US Federal Register, 1998). Under the current regulations ships are required to report whether the exchange has occurred. Therefore, regulators and enforcement agencies are faced with the challenge of verifying whether ships are accurately reporting ballast status and complying with the voluntary guidelines. Verification of whether or not a ship has exchanged its ballast water in mid-ocean, can involve several approaches. We have selected optical properties of sea water as on potential independent method of verification. Previous data suggest that DOM (dissolved organic matter) UV fluorescence, expressed as high resolution EEM (excitation emission matrix) spectra, has definite potential as a tool for discriminating between coastal and mid-ocean water. Accordingly, samples were collected for EEM spectral analysis during a trans-Pacific voyage of chemical carrier were used to test methodologies for assessing the efficacy of the UV fluorescence of DOM as a means of verifying at sea exchange. The data demonstrated a clear difference between the optical characteristics of ballast water collected before and after mid-ocean exchange. After each exchange, the optical signatures shifted from signatures typical of the coastal water at the donor ports, to those typical of the mid-ocean water during the exchange. The shifts were concomitant with a marked reduction in the concentration of a tracer dye added to the ballast tanks prior to
departure from the ports of origination. A shift in the optical signatures was not observed in the control (non-exchanged) tank. The work has shown relative consistency in the optical signatures of mid-ocean water, which suggests that there is a very limited presence of DOM fluorophores in mid-ocean. Strong humic-like and protein-like signatures in the EEMs of coastal water and in the ballast water taken up by the ship in port were identified. The similarity in the EEMs of ballast water samples collected
after mid-ocean exchange and the EEMs of samples collected from the mid-ocean during the exchange, demonstrated that there was no significant source of fluorescence ontamination within the ballast tanks themselves. Hence, the development of fluorescence based technologies as a tool for verifying mid-ocean ballast water exchange shows great potential.

Author to contact: Carlton Hunt
Battelle
397 Washington St.
Duxbury, MA 02332
(781) 952-5374 Phone
(781) 934-2124 Fax
Huntc@Battelle.org

PREDATION BY THE RED ROCK CRAB, *CANCER* PRODUCTUS, ON THE EUROPEAN GREEN CRAB, *CARCINUS MAENAS*

Christopher Hunt and Sylvia Behrens Yamada

Key words: green crab, *Carcinus maenas*, *Cancer productus*, predation, estuary

In Yaquina Bay, Oregon, we observed very little overlap in the distribution of the invasive green crab, *Carcinus maenas*, and the red rock crab, *Cancer productus*. Red rock crabs dominate the more saline, cooler lower estuary and green crabs, the less saline, warmer upper estuary. McDonald et al. (1998) observed a similar distribution pattern in Bodega Harbor, California. Since caged green crabs survive well in the lower estuary, we decided to test the hypothesis that red rock crabs prey on green crabs and thus exclude them from the more physically benign lower estuary.

A laboratory species interaction experiment was set up to determine whether red rock crabs prey on smaller green crabs at a higher rate than on smaller crabs of their own species. Crabs of both species were collected and sorted by weight into three size classes: small, medium and large. Small and medium crabs of both species were paired with green crabs or red rock crabs of various sizes. Crab pairs were housed in individual arenas and allowed to interact for 7 days. When cabs were paired up with their own species, mortality was less than 10%, even in the presence of a larger conspecific. Smaller red rock crabs survived well in the presence of larger green crabs, but the reverse was not true. When small green crabs (60-67 mm carapace width) were matched with medium and large red rock crabs, their mortality increased to 52% and 76% respectively. A less dramatic pattern was observed for medium green crabs (73-80 mm) (Figure 1). Thus on the West Coast of North America, the more aggressive red rock crab, *Cancer productus*, appears to keep *Carcinus maenas* out of the more saline and cooler lower estuaries.

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Author to contact: Sylvia Behrens Yamada
Zoology Department, Oregon State University
Corvallis, OR 97331-2914, 541-737 5345
Telephone: 541-737 5345
Fax: 541 737-0501
e-mail: yamadas@bcc.orst.edu

GAS SUPERSATURATION, A NOVEL AND ENVIRONMENTALLY FRIENDLY METHOD FOR ELIMINATING UNWANTED ORGANISMS IN BALLAST WATER AND OTHER WATER BODIES

Anders Jelmert

Institute of Marine Research, Austevoll Aquaculture Research Station

Key Words: Supersaturation, ballast water , invasion

Gas supersaturation is known to affect various aquatic biota. When aquatic multicellular organisms are exposed to gas supersaturated water, and especially when subsequently subjected to lowered hydrostatic pressures, they are suffering from embolism and hemorrhages. If the level of supersaturation is high enough, the condition may be lethal. Also sublethal exposures represent a considerable stress to the organisms. While lethal effects occationally have been observed in natural or semi-natural conditions, we have suggested it can be optimized and used to prevent the transfer of unwanted organisms translocated via ballast water (1). The susceptibility to gas supersaturation varies between the different systematic groups of organisms such as molluscs *Mya arenaria* at 114% (2), and *Argopecten irridans* concentricus at 116% (3), subadults of the saltwater tilapia *Oreochromis spilurus*, at 112% (4), larvae of the white sturgeon *Acipenser transmontanus* at 131% (5) We would not expect gas supersaturation to affect the microbial community directly, but the breakdown of dead and moribund macrobiota may lead to shifts in the species composition in the micobial community. Results from tests on the effect of gas supersaturated (air and nitrogen + air) seawater on the brine shrimp *Artemia* sp. and juveniles of the common mollusc *Mytilus edulis* will be presented and discussed. The method offers two major advantages. No need for storing or handling harmful chemicals, and secondly, no harmful chemical substances released when treated water is discarded. General applications and limitations of the method will be outlined

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Author to Contact: Jelmert, A.
Institute of Marine Research
Austevoll Aquaculture Research Station
N-5392 Storebø, Norway.
E-mail: anders.jelmert@imr.no
Phone +47 56 18 03 42
Fax: +47 56 18 03 98

TROJAN VESSELS: DOMESTIC BALLAST WATER VOYAGE PATTERNS IN THE UNITED STATES

Joel A. Kopp

Graduate Fellow, Smithsonian Environmental Research Center,
Smithsonian Institution

Key Words: ballast water, aquatic nonindigenous species, National Invasive Species Act, coastwise shipping

Ballast water transported by ships is recognized as an important vector for the transfer and introduction of aquatic organisms between coastal ecosystems around the world. The United States primarily pays attention to the international dimension of this problem, as evidenced by the National Invasive Species Act of 1996, which requires ships entering U. S. waters that intend to discharge ballast to report their ballast water information and activity, and requests them to exchange ballast at sea, but exempts ships engaged in most coastwise voyages from any such provisions. The result of this international focus is that patterns of ballast water transfer into the United States are beginning to be documented and analyzed, but transfers between ecosystems within the United States remain poorly understood.

There is substantial scientific justification for an equal level of concern about coastwise ballast voyages. It is known that plankton survival in ballast tanks is inversely proportional to voyage duration (Cohen, 1998). Since coastwise voyages tend to be shorter than international voyages, it is reasonable to assume a higher rate of plankton survival in the ballast that is transported in coastal voyages. It is also known that some U. S. ports have nonindigenous species that others do not. The San Francisco estuary, for instance, contains numerous nonindigenous aquatic species that do not occur elsewhere on the west coast, most of international origin (Cohen, 1998). Transfers of ballast from invaded ports to uninvaded ports increases the risk of the spread of these invasions. The United States, though one country, is home to many varied ecosystems along the coasts of its states, and transfers of ballast water between these ecosystems are no different from a biological perspective than transfers of ballast between ecosystems in different countries.

This paper analyzes domestic voyage data collected from the U. S. Maritime Administration and the U. S. Army Corps of Engineers in order to document patterns of coastwise ballast water transport in the United States. Ballast water profiles are presented for major bioregions of the country, as well as for individual states and over 60 ports. For each of these locations, these profiles show where ballast water is received from and sent to and how many voyages are involved. These voyage patterns may be useful in predicting what areas are at risk of invasion from other invaded areas. Comparison is made to international ballast voyage patterns for selected areas. Limitations of the data are also discussed, as are recommendations for changes to the National Invasive Species Act when it is up for renewal in 2002.

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Author to Contact: Joel A. Kopp
4747 30th Ave. NE #F144
Seattle, WA 98105
phone: 206-729-8572
email: kopp@u.washington.edu

EFFECTS OF THE NON-NATIVE CRAB *HEMIGRAPSUS SANGUINEUS* ON CRAB COMMUNITY DIVERSITY AT EDITH REED SANCTUARY (RYE, NY) FROM 1998-2000

Kraemer, George P. & Sellberg, Monica

Key Words: *Hemigrapsus*, biodiversity, intertidal, crab

The Japanese Shore Crab *Hemigrapsus sanguineus* was first reported in the western end of Long Island Sound in approximately 1994. Populations of *H. sanguineus* and the native crabs *Dispanopeus sayi*, *Carcinus maenas*, and *Cancer irroratus*, have been monitored since 1998 at Edith G. Reed Sanctuary (Rye, NY). Quarterly vertical transects have been recorded since June, 1998 to describe densities, vertical distributions, and species composition within the rocky intertidal zone. Recent measurements of numerical density have also been translated using empirical size-weight relationships into biomass density. The objective of this study has been to follow intertidal populations of crabs in an effort to document effects of the introduction of *H. sanguineus* on potential competitors. Toward this end, data from June, the period of high crab abundances in the intertidal, have been compared over three years.

In June 1998, *H. sanguineus* were already more abundant than native crabs (52% vs. 48%, respectively). Populations of *H. sanguineus* and *D. sayi* (the numerically dominant crab) reached higher densities and had broader intertidal distributions than did the two other native species. In June 1999, although the number of crabs captured had increased there was no change in the relative abundance of *H. sanguineus* and native crabs in the intertidal zone. The dominance by *H. sanguineus* increased to 99% of individuals in June 2000, at which time native crabs were not recorded above approximately mid-tide. June 2000 *H. sanguineus* densities were as high as 105 crabs m-2, while the maximum native crab density was only 2 crabs m-2. Average June densities (crabs m-2) of *H. sanguineus* had increased by almost eight-fold from 1998-2000, while the density of native crabs decreased by 96% over the same interval. In June 2000, the [*H. sanguineus* : native crab]biomass ratio averaged 48:1 across the intertidal zone.

Since 1998, the biodiversity of the summer crab community in the rocky intertidal zone at Edith Reed Sanctuary has decreased greatly; species richness in the intertidal decreased by 40%, while species diversity measured by Shannon's H' decreased by 91%, due primarily to an 82% decrease in evenness (J). Whether these decreases have occurred throughout the Long Island Sound, and whether the native crab populations rebound await further sampling.

On small spatial scales the distribution of *H. sanguineus* at Reed Sanctuary appears to be habitat-limited. While habitat use by *H. sanguineus* and *D. sayi* overlaps, the latter species may have a natural refuge in its broader substrate tolerance. *D. sayi* can inhabit finer grained sediments while *H. sanguineus* is restricted to cobble - boulder substrates with planar projected areas greater than ca. 20 cm2.

Author to Contact: G. Kraemer
Division of Natural Sciences
Purchase College
735 Anderson Hill Road
Purchase, NY 10577, USA
Email: gkraemer@purvid.purchase.edu
tel: 914-251-6640
fax: 914-251-6635

THE GULF OF MEXICO REGIONAL PANEL: YEAR ONE ACTIVITIES

Herb Kumpf

NOAA/National Marine Fisheries Service

Key Words: Gulf of Mexico Regional Panel, aquatic nuisance species, Gulf of Mexico Program

A regional, multi-jurisdictional approach to the aquatic nuisance species issue is emphasized in the National Invasive Species Act of 1996. The Act encourages the development of Regional Panels by the national Aquatic Nuisance Species Task Force (ANS Task Force) to advance prevention and control efforts. These panels serve in a voluntary capacity to provide the ANS Task Force with (1) regional input on emerging invasive species issues, (2) coordination of regional control programs, and (3) recommendations on policy and/or program actions to be undertaken at the national level by the organizations represented on the ANS Task Force.

The Gulf of Mexico Program (GMP) is an intergovernmental, community-based program dedicated to managing and protecting resources of the Gulf of Mexico in ways consistent with the economic well-being of the region. One goal of the GMP is to sustain living resources in the Gulf of Mexico. A primary objective to achieve this goal, the GMP will support implementation, by 2009, of voluntary or incentive-based practices and technologies that can prevent new introductions of nonindigenous species, or reduce the impact or range of dispersal of known nonindigenous species, as identified by the five Gulf States.

To support Gulf-wide coordination and communication of nonindigenous species issues, the GMP convened, beginning in 1997, a multi-stakeholder, technical-level Nonindigenous Species Focus Team (NSFT). Through 1999, the NSFT primarily focused on two priority issues -ballast water as a major introduction pathway and shrimp viruses - and NSFT stakeholders sponsored three ballast water workshops, two shrimp virus workshops, and a Gulf of Mexico Nonindigenous Aquatic Species Workshop.

Due to the regional focus of the GMP on nonindigenous aquatic species issues, in September 1998, the ANS Task Force invited the NSFT to serve as the nucleus of the Gulf of Mexico Regional Panel. The GMP determined that the structure of its Management Committee is ideally suited to serve as the Regional Panel, by virtue of its broad organizational management representation. In January 2000, the GMP's Policy Review Board approved a resolution to have the Management Committee serve as the Gulf of Mexico Regional Panel. The NSFT continues in its present form and assists the Gulf Panel by formulating technical characterizations, recommending annual program workplan goals, recommending priority projects, and developing a public communication and education program.

In September 2000, the NSFT issued the report An Initial Characterization of Nonindigenous Aquatic Species in the Gulf of Mexico Region (www.gmpo.gov/species/initialspecies.html). This detailed issue-characterization serves as a regional information and coordination resource for nonindigenous aquatic species management and research activities in the Gulf of Mexico region. It also begins to compile information that will assist the five Gulf States in developing their comprehensive nonindigenous species management plans.

In February 2001, the Gulf of Mexico Regional Panel issued its 2000 Annual Report (www.gmpo.gov/species/annualreport.html). In addition to making recommendations to the ANS Task Force and highlighting selected successes of the Gulf-region management community, this public information resource describes the aquatic nuisance species issue in the Gulf of Mexico region and provides fact sheets on some of the more critical aquatic nuisance species.

Over the next year, the Gulf Panel and the NSFT will continue issue characterization activities, further investigate ballast water management options for the Gulf region, support at least three invasive species prevention/reduction projects in the Gulf region, and establish a pilot education/outreach program in the State of Mississippi. In addition, considerable effort will be spent supporting the Gulf States prepare aquatic components of state comprehensive nonindigenous species plans.

Author to Contact: Herb Kumpf
NOAA/National Marine Fisheries Service
3500 Delwood Beach Road
Panama City, FL 32408
P: 850-234-6541 x203
F: 850-235-3559
Email: herb.kumpf@noaa.gov

BIOCONTROL OF THE COCONUT MOTH OF FIJI: WHAT HAPPENED AND WHY?

Armand Kuris

University of California, Santa Barbara

Key Words: biological control, Coconut moth, Levuana iridescens, safety, Fiji

In 1925, J. D. Tothill, and two British colleagues set out to manage Levuana iridescens, the coconut moth of Fiji, using biological control. By 1930, they had succeeded so completely that this pest of the copra crop was scarcely to be found and they had summarized their campaign in a thoroughly documented and well-illustrated monograph, published for the government of Fiji by the Imperial Bureau of Entomology. This event is of importance today because it stands as the first apparent extinction of a species due to scientific biological control. This episode figures prominently in the literature that stimulated our current concern for the safety of modern biological control. Fortunately, Tothill et al, (1930) so well documented their work that not only what they did can be evaluated, but also, their motivations are available for discussion. Hence, the technical events, their ecological consequences, and the values of the time can be viewed in the light of modern considerations.

The example of the coconut moth has been presented in the modern literature as one in which a unique, beautiful, endemic moth became extinct soon after a generalist tachinid fly, *Bessa* (=Ptychomyia) *remota*, was introduced from the Federated States of Malaya (e. g., Howarth 1991, Barratt et al, 2000). Thus, it seems to be an example of the now highly controversial practice of neoclassical biocontrol (Lockwood 1993); in which an introduced natural enemy is used against a native pest. However, the geographical origin of the coconut moth was quite uncertain in 1925 (and perhaps still is today). Further, its alleged extinction has never been sufficiently investigated nor authoritatively verified.

Was biocontrol of the coconut moth a risky thing to attempt in the 1920s? Was it improper in terms of the values of today? Tothill et al. (1930) present the reasons for the government of Fiji and Britain considering the control of the coconut moth a matter of the utmost concern. Perhaps surprisingly, the impetus for this control program was not primarily economic. Rather, control of the coconut moth was undertaken to protect the culture of the fijians and other melanesian, polynesian and micronesian peoples of the Pacific. This objective puts some important values in conflict, even from the perspective of a modern (Western millenial) viewpoint.

Finally, consideration of this historic example may aid the risk assessment of biocontrol agents against introduced marine pests. The overall goal, to paraphrase Eldredge Cleaver, is to be part of the solution, not just part of the problem.

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Author to Contact: Armand Kuris
Marine Science Institute
University of California
Santa Barbara, CA 93106
Tel. (805) 893-3998
fax: (805) 893-4724
Mailto: kuris@lifesci.ucsb.edu

FEASIBILITY OF COASTAL OCEAN OBSERVING SYSTEMS FOR MONITORING INVASIVE SPECIES: A PROPOSED NEAMGLL-RARGOM WORKSHOP

Kuzirian, Alan M., Marine Biological Laboratory, Woods Hole, MA;
Ivar G. Babb , National Undersea Research Center, University of Connecticut, Groton, CT;
William M. Wise, Marine Sciences Research Center, State University of New York-Stony Brook, Stony Brook, NY

Key Words: Invasive Species, Coastal Ocean Observing Systems, NEAMGLL, RARGOM, LabNet

Introduced species have been a problem in the marine and coastal environments for centuries. Historically, many of these introductions have a strong geophysical component often associated with natural disasters. However in more recent times, "man, the supreme meddler" (Laycock, 1966) has dramatically changed the rate, number, and geography of exotic species invasions through importation, transportation, intentional releases related to agriculture or aquaculture, as well as unintentional escapes. Indeed, Noah and his ark typifies man's interposition into what was a natural process. During the last century, the problem has been dramatically accelerated with the advent of modern high-speed freighters and their methods of ballast water exchange.

Invasive species have had enormous ecological and economic impacts on terrestrial and aquatic environments. Their economic cost to Americans alone is estimated at $137 billion annually, and up to 46% of the Federally listed endangered species have been impacted in some way by invasive species. The dramatic proliferation and enormous human impact of the zebra mussel (*Dreissena polymorpha*) actually catalyzed the passage of the Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990 (P.L. 101-646), that established an institutional infrastructure and programs to prevent unintentional introductions, coordinate research, control and disseminate information, develop and carry out sound control methods, minimize economic and ecological impacts, and establish a research and technology program.

The invasive issue remains an important topic within the U.S. national research and monitoring agenda and prompted the recent (February 1999) Presidential Executive Order (13112) which established a National Invasive Species Council comprised of the leaders of eight Federal Departments their constituent agencies and non-Federal support staff. The charge to the Council was to develop a plan "to minimize the economic and ecological impacts and the harm to animal and human health associated with invasive species." Their National Invasive Species Management Plan (NISMP), Meeting the Invasive Species Challenge, was just released, 18 January 2001. While much of this impact is attributable to terrestrial invasive species, there is increasing interest and concern over invasions in aquatic systems.

Programs that document species invasions are becoming established for the early detection of introductions. Early detection and quick response can eradicate or contain invasive species much more effectively than long-term control measures that may be infeasible or expensive. An integrated approach involving research and development, and technical assistance is required to deal with this issue, but unfortunately, no such comprehensive national system exists currently (NISMP, 2001).
Funding for research and monitoring efforts are viewed as essential in the response to invasions and grant programs to support multi-disciplinary, regional approaches are mentioned as being particularly helpful to address widespread invasions.

Two principal regional scientific organizations that focus on environmental resources of U.S. Northeast marine and Great Lakes regions are the Northeast Association of Marine and Great Lakes Laboratories (NEAMGLL) and the Regional Association for Research on the Gulf of Maine (RARGOM). These organizations are proposing a jointly sponsored workshop to assess the potential role of Coastal Ocean Observing Systems (e.g. Coastal GOOS; regional GOMOOS; local LEO-15) as major elements in a coordinated, regional effort to monitor invasive species. The goal of the proposed workshop would be to develop a monitoring and research strategy that utilizes these ocean observing systems as sentinel sites to monitor the introduction, distribution, spread, ecological, and economic impact of non-native species, both

benthic and pelagic. Such a monitoring program could be incorporated into the data sampling, archiving, and distribution facilities being developed for the Coastal Ocean Observing System data sets.

The proposed project would use the capabilities of NEAMGLL member institutions and others in the Northeast and Great Lakes regions, as well as the extant coastal observing systems and programs that are under development or already functional, to establish a capability to systematically and comprehensively document the occurrence, abundance, distribution, origins, and ecological and/or economic consequences of aquatic species invasions in the region. This information is vital to studies that would explore the underpinning dynamical processes that characterize these invasions.

Data and integrative data products from the monitoring network would be made available through the LabNet® system developed by the National Association of Marine Laboratories (NAML). LabNet® allows access to distributed environmental data bases located at participating NAML member institutions (and other participating organizations) to provide visually-integrated environmental data ('real' time and historic) on temporal and geospatial scales via the World Wide Web. Making the data from the proposed invasive species monitoring network available through LabNet® is a critical aspect of the overall project. This linkage will provide scientists, environmental resource managers, educators, and others interested in aquatic invasive species in the Northeast with a simple, no-cost means to access data being collected by a variety of different institutions at multiple locations in the Northeast.

To initiate this project, these two organizations propose to fund a workshop of invited participants with expertise in these issues to develop a sampling and monitoring protocol that takes advantage of the immense infrastructure being proposed for the coastal observing system. The goals of the workshop would be to: 1) design a field sampling protocol to monitor the distribution and abundance of invasive aquatic species, 2) to assess the suite of data being collected at coastal observatories as parameters with which to develop a predictive capability of the success, rate, trajectory etc. of invasions, 3) to describe the requirements for each participating institution to integrate with LabNet®, 4) to identify the organizations in the Northeast and Great Lakes regions that would be involved in the monitoring effort, 5) to identify sources of funding to initiate and maintain the monitoring effort, and 6) to establish a management team drawn from the participating organizations that will move the project through its succeeding steps. This organizing workshop is proposed for the fall of 2001.

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Author to contact: Kuzirian, Alan M.
Marine Biological Laboratory
Woods Hole, MA
phone, 860/405-9121
fax, 445-2969
Email: babb@uconnvm.uconn.edu

THE EFFICACY OF PARASITIC CASTRATORS IN BIOLOGICAL CONTROL PROGRAMS

Kevin D. Lafferty

United States Geological Survey

Western Ecological Research Center

Key words: green crab, *Carcinus*, biological control, parasites, model

Many insect-pest biological control efforts have used host-specific parasitoids to provide targeted and effective regulation of a pest population. In marine systems, parasitoid life histories are relatively uncommon. Parasitic castrators, however, are common in aquatic habitats and are similar to parasitoids in some ways. Because parasitic castrators can often reach high prevalences, it seems plausible that they may play an important role in regulating host populations. This suggests that parasitic castrators could be useful biological control agents in marine systems. My goal was to understand the conditions under which parasitic castrators would reduce host population density and to predict patterns that could be seen in the field. I used simple differential equations and data from field studies of the European green crab, *Carcinus maenas*, to determine how parasitic castrators might depress host density. I expected that the ability of a parasitic castrator to regulate its host and the extent to which it depressed host density would vary depending on the nature of host-parasite population dynamics. In particular, I compared resource and space-limited host populations and open and closed recruitment of hosts and/or parasites. The main pattern that I explored was the association between the prevalence of a parasitic castrator and the density of the host population. The analytical results indicated that as long as host recruitment was closed, equilibrium host densities lay along a line or curve that declined with the equilibrium prevalence of the parasite. However, there were important differences between space and resource-limited populations. Space-limited populations that normally did not reach a high percent cover were less invasible by a castrator and, when invasible, less impacted by a parasitic castrator relative to otherwise identical populations regulated by resource limitation. Space-limited populations that normally reached a high percent cover (as might be expected by an introduced pest) were more affected by a parasitic castrator than if they were resource limited. The recruitment dynamics of the parasite also affected the interaction. Parasites with open recruitment could depress the host population and even cause it to go extinct, but did not regulate it in the traditional sense. I simulated host-parasite equilibria by generating random combinations of the key parameters to help translate the analytical results into predictions that would be useful for comparison with field data. For the green crab data, there was a negative association between prevalence and density, suggesting that *Sacculina carcini* reduced green crab density and that green crab recruitment was not open at the scale the data were sampled. These data were statistically most consistent with the random equilibria generated by the resource-limited, parasite-closed model. In conclusion, because parasitic castrators can regulate and significantly depress host populations (so long as they exist across spatial scales where the host has closed recruitment), parasitic castrators may be effective biological controls for introduced marine species. These results do not necessarily imply that *S. carcini* is an appropriate biological control agent, because appropriateness for use in biological control requires strict host-specificity so as to minimize non-target effects.

Author to contact: Kevin D. Lafferty
C/o Marine Science Institute
University of California, Santa Barbara
Santa Barbara, California 93106
United States of America
805 893 8778, fax: 805 893 8062
Email: Lafferty@lifesci.UCSB.edu

SPATIAL PATTERNS AND ASSOCIATIONS OF NONINDIGENOUS BENTHOS IN THE SAN FRANCISCO ESTUARY

Henry Lee II (U.S. EPA, Western Ecology Division, Coastal Ecology Branch), Bruce Thompson (San Francisco Estuary Institute), and Sarah Lowe (San Francisco Estuary Institute)

Key Words: San Francisco Estuary, nonindigenous species, benthic assemblages, sediment contamination

The pioneering work by Carlton, Cohen, and their colleagues has demonstrated that San Francisco Estuary is one of the most invaded aquatic system in the United States. The present study builds upon this work by evaluating the spatial patterns of invasion among subtidal habitats and the relationship of nonindigenous species to both native species and sediment contamination. Using the results from the 1994 to 1997 Regional Monitoring Program (RMP), the subtidal benthos of San Francisco Estuary was divided into seven assemblages based on community structure (Thompson, et al., 2000). Using this classification as a framework, both the proportion of species classified as nonindigenous species and the proportion of total individuals classified as nonindigenous were calculated for each assemblage (Table 1). The most invaded assemblages were the Main Estuarine and Estuarine Transition assemblages with over 90% of the individuals and about 60% of the species consisting of nonindigenous species. An invasive clam, *Potamocorbula amurensis*, was the dominant species in both assemblages and excluding it resulted in similar percents of nonindigenous abundances in five of the seven assemblages (Table 1). In contrast to the high abundances of nonindigenous organisms in all the other assemblages, only 7% of the individuals were nonindigenous in the Central Bay Marine Sandy assemblage. This assemblage is characterized by a low density and low number of species, suggestive of a harsh environment. However, the Fresh-Brackish site also had low diversity and abundance but had a similar extent of invasion as the other sites within the estuary.

To assess the strength of the relationship between introduced and native species, we determined the proportion of the variation (R2) in native organisms explained by nonindigenous organisms in multiple regressions that included abiotic and biotic parameters. In the Main Estuarine assemblage, the abundance of nonindigenous organisms explained little of the variation in the abundance of native organisms. However, there was a moderately strong relationship between the number of native species and both the number of nonindigenous species (R2=0.62) and the abundance of nonindigenous organisms (R2=0.58). In the Central Bay Muddy Assemblage, nonindigenous species explained only about 13% of the variation in number of native species and 31% of the variation in the abundance of native organisms. Spearman's rank correlations were calculated between the numbers of native and introduced species and between the abundances of native and introduced organisms. Of the 14 possible correlations, 9 were significantly positive, ranging from 0.25 to 0.60. There were no significant negative correlations. These results suggest that there are not strong, consistent associations between native and nonindigenous species, while the positive associations suggest that both nonindigenous and native taxa are responding similarly to small?scale differences in habitat quality.

One approach to determining whether contaminated sites were more heavily invaded was to

compare the Estuarine Margin assemblage, which has the characteristics of an impacted benthic community, to the other estuarine assemblages. The Estuarine Margin had a smaller proportion of nonindigenous taxa and individuals than either the Main Estuarine or the Estuarine Transition assemblages. The lower abundance of nonindigenous taxa in the Estuarine Margin was due to the low density of *P. amurensis* (0.2%) and excluding this species resulted in similar percentages in the three estuarine assemblages (Table 1). Another approach was to plot both the number of nonindigenous species and their abundance along sediment contamination gradients as measured by the mean Effects Range Median quotient (mERMq), which was based on 13 contaminants for which there are ERM guidelines. Although the number of samples at higher mERMq (i.e., more contaminated) values was limited, there was no indication that the number of nonindigenous species or their abundances increased with contamination. These results are consistent with the observation that introduced benthic species vary widely in their responses to sediment contamination. In a previous study in San Francisco Bay, the introduced amphipod

Ampelisca abdita displayed a high sensitivity to sediment contamination along a DDT gradient. In contrast, another introduced amphipod, *Grandideriella japonica*, was tolerant to high concentrations of DDT. The low abundance of P. amurensis in the Estuarine Margin assemblage suggests that this introduced species is sensitive to sediment contaminants.

These results clearly demonstrate the pervasiveness of introduced species throughout the subtidal benthic communities of the San Francisco Estuary. They also demonstrate that even within a highly invaded system there can be relatively uninvaded habitats. The positive associations between native and nonindigenous species suggest they are both responding to similar fine?scale differences in the benthic habitat. They do not necessarily demonstrate a lack of negative interactions (e.g., competition). The positive associations were determined in an already highly invaded community and a temporal study might well have shown a decline in native species with the increase in introduced species. Finally, there is no indication that sediment contamination, a type of disturbance, promotes nonindigenous species or that nonindigenous benthic species as a group are more tolerant to sediment contamination.

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Author to contact: Henry Lee II,
U.S. EPA
2111 S.E. Marine Science Drive
Newport, OR 97365
Telephone: 541-867-5001
FAX: 541-867-4049
Email: lee.henry@epa.gov

ORIGIN AND IDENTITY OF INVERTEBRATE ORGANISMS BEING BROUGHT INTO CANADA'S PACIFIC COAST BY BALLAST WATER

Colin D. Levings, Nara Mehlenbacher and Karen Barry

In a project assessing colonization risk of ballast water organisms, the originating locations and identity of flora and fauna being brought into Canada's Pacific coast were determined using indirect and direct methods. A data base provided by the Vancouver Port Authority from about 400 ships enabled us to plot the start and end positions where ballast water exchanges took place in the north Pacific Ocean. The lines joining the start and end positions, which we called exchange transects, were on average about 400 km long with a very large variation. The exchange transects were plotted on a GIS display and then overlain on North Pacific water masses to determine their overlap with particular temperature and salinity regions and known zooplankton assemblages. Another part of the project involved an empirical investigation of the changes in invertebrate communities after before and after midocean exchange. The crew of MV SKAUGRAN took a biological sample in a ballast tank after filling at a northwest Pacific port and then again after the water in the tank had been exchanged in mid ocean. Preliminary results showed that mid ocean exchange south of the subarctic boundary likely result in the ballast water community being dominated by deep ocean, stenohaline and stenothermal organisms. However because the exchange process is relatively inefficient, coastal organisms are always present in low numbers and are potentially colonizers when the water is disposed of in Canadian waters. Colonization risk is likely higher with the exchange transects in the northeast Pacific, which tend to be closer to the coast.

Author to contact:
Colin D. Levings
Coastal and Marine Habitat Science Section
West Vancouver Laboratory
4610 Marine Drive
West Vancouver, British Columbia V7V 1N6, Canada

A FRAMEWORK FOR EMPIRICAL RESEARCH ON ALIEN SPECIES

Andrew M. Lohrer

North Inlet - Winyah Bay National Estuarine Research Reserve, Baruch Institute for Marine Biology and Coastal Research, University of South Carolina

Key Words: invasive marine species; niche theory; research framework

The concept of the niche was developed decades ago as an explanation for how species co-exist in ecological communities (e.g., Grinnel, 1917; Elton, 1927; Gause, 1934; Hutchinson, 1957). In the ensuing years, however, niche theory was heavily criticized and many eloquent arguments have been made to demonstrate its limitations (reviewed by Abrams, 1983). For example, while indices were developed to quantify niche overlap, these metrics yielded little information about the intensity or outcome of competition (Colwell and Futuyma, 1971). Furthermore, because the niche was defined as an n-dimensional entity, the amount of niche overlap between species may be impossible to accurately characterize. Also, many factors besides competition are acknowledged as important determinants of community composition [e.g., disturbance (Dayton, 1971; Sousa, 1979a, 1979b); predation (Paine, 1966; Caswell, 1978); timing and density of propagule supply (Sutherland and Karlson, 1977; Underwood and Denley, 1984; Roughgarden et al., 1985); environmental variability (Chesson and Warner, 1981)]. Some researchers suggest that the theory is rarely (if ever) useful because species populations are rarely (if ever) at equilibrium (e.g., Caswell, 1982).

Despite all the criticisms that have been levied, the concept of the niche remains a foundation for many central themes in the field of ecology and helps researchers comprehend the roles of species in communities (Begon et al., 1996). As long as niche theory is considered together with its amendments, it has a great deal of utility when applied to modern ecological investigations (Chesson, 1991). Here, niche theory is re-visited and re-emphasized to better understand successful invasions by exotic species.

While factors affecting invasive success by exotic species have been extensively studied (e.g., O'Connor, 1986; Ehrlich, 1986, 1989; Hobbs, 1989; Case, 1990; Rejmánek and Richardson, 1996; Williamson and Fitter, 1996; Tilman, 1997; Stachowicz et al., 1999, Levine, 2000), there is no general consensus as to which species will invade which communities. Here, based on a wealth of experimental and theoretical literature, a series of niche-based models were developed into a framework. While this is not the first time that ecological niche theory has been applied to the problem of biological invasions (reviewed by Herbold and Moyle, 1986; Colwell, 1992; Williamson, 1996), multiple alternative models have not been brought together and presented in this fashion before. The goal of the framework was to create testable hypotheses characterizing alternative modes of successful invasion by exotic species.

The niche-based framework (NBF) seeks to explain (a posteriori) why particular species successfully invade new habitats. Ideally, every new invasion that has recently occurred (whether terrestrial, freshwater, or marine) will be explained by one (and only one) of the models in the framework. The explanatory nature of the framework has two advantages. First, it does not rely on correlative evidence to explain invasion success. The NBF acknowledges that multiple types of invasions can occur and it seeks to explain them separately, on a case-by-case basis. Theoretical and correlative approaches used in the past have lumped multiple invasions together and, as a result, there are very few compelling patterns (see reviews by Vermeij, 1996; Williamson, 1996; Wiser et al., 1998). Second, the NBF explains scenarios that support prevailing hypotheses--for example, how disturbance can promote invasion success (e.g., DeFerrari and Naiman, 1994; Hobbs, 1989) or how species richness can affect resistance to invasion (Robinson et al., 1995; Tilman, 1997; Stachowicz et al., 1999; Levine, 2000)--and it explains why there are exceptions to those ideas as well. Third, while it is not yet known which NBF models occur most frequently, these are simply statistical problems that can be addressed over time as more invasions are studied using this framework (i.e., a database needs to be created). When the niche-based framework is widely applied, invasion ecologists may begin to elucidate patterns necessary for making predictions.

The NBF models (Fig. 1) are differentiated hierarchically according to (1) the amount of niche overlap in the invaded habitat, (2) the type/amount of change in niche breadth between native and invaded habitats, and (3) the nature of resource limitation. While the NBF models explain several kinds of invasions in a conceptual sense, niche-based mechanisms of real invasions may not be so easily distinguished. The

methods of data collection will most likely be specific to the type of organism/system being studied. However, these general guidelines are offered as an aid for investigating invasions on a case-by-case basis: (1) The alien must be studied shortly after its first appearance in the invaded habitat so that early, post-introduction changes can be detected (Strong et al., 1977). After an alien becomes well integrated into a community, it is more risky to speculate on the mechanisms of its invasion. (2) Data must be collected for species that co-occur with the alien (i.e., guild members that may utilize resources that the alien requires). (3) Data must be collected on several relevant dimensions of the niche. If resource use of a guild is similar along one dimension of the niche, it may be dissimilar along another (Cody, 1968; Schoener, 1974; Emmons, 1980; McKenzie and Rolfe, 1986). Therefore, particular care is needed when testing high niche overlap invasion models. (4) Data must be collected in the native and invaded habitats of the introduced species and sampling protocols must be standardized so that the data can be compared without bias.

The NBF is not a predictive framework in the truest sense since it seeks to explain particular invasions after they have occurred. However, the NBF generates predictions and provides suggestions for testing them. The breadth and utility of the framework will likely increase as more invasions are studied under NBF guidelines. Because the rate of new invasions is apparently increasing in some habitats (Cohen and Carlton, 1998) and because the problem of biological invasions is global in scale (Elton, 1958; Drake et al., 1989; Carlton, 1987; Allen and Flecker, 1993; Carlton and Geller, 1993; Williamson, 1996; Simberloff and Von Holle, 1999), sample size for an NBF database should increase fairly rapidly. Once enough invasions have been characterized, the most common mechanisms of species invasion will become clearer.

Figure 1. Hierarchical niche-based framework (NBF). The models are differentiated according to (1) the amount of niche overlap in the invaded habitat--the uppermost level, (2) the type/amount of change in niche breadth between native and invaded habitats--the second level, and (3) the nature of resource limitation--the final level. There are 10 possible paths, each representing a unique invasion scenario.

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Author to Contact: Andrew M. Lohrer
North Inlet - Winyah Bay National Estuarine Research Reserve
Baruch Institute for Marine Biology and Coastal Research
University of South Carolina, Baruch Marine Field Laboratory
PO Box 1630, Georgetown, SC 29442
(843)546-3623 [phone]
(843)546-1632 [fax]
Email: lohrer@belle.baruch.sc.edu

SPATIAL AND TEMPORAL ANALYSIS OF TRANSOCEANIC SHIPPING VECTORS TO THE GREAT LAKES

Hugh J. MacIsaac[1], Robert I. Colautti[1], Arthur J. Niimi[2], Colin D.A. van Overdijk[1], E.L. Mills[3] and K. Holeck[3]

[1] Great Lakes Institute for Environmental Research, University of Windsor, Windsor, ON N9B 3P4 Canada
[2] Department of Fisheries and Oceans, Canada Centre for Inland Waters, Burlington, ON L7R 4A6 Canada
[3] Department of Natural Resources, Cornell University Biological Field Station, Bridgeport, NY, USA 13030

Key Words: Great Lakes, ballast water, ship vectors

The Great Lakes of North America have been invaded and profoundly affected by introduction of nonindigenous species (NIS). Release of ballast water by transoceanic commercial ships has been the strongest vector of NIS to the Great Lakes during the 20th century. Here we review spatial and temporal patterns of ballast release by foreign, transoceanic ships entering the Great Lakes system with saline ballast water (BOB ships) and those that enter the system with cargo but which load and subsequently discharge ballast water within the lake system (NOBOB ships). Even though a large percentage (79.5%) of in-bound ships stop at ports on Lake Ontario or Lake Erie as their first port-of-call, a disproportionate percentage of ships (52%) discharge saline ballast water into Lake Superior. Similarly, a disproportionate fraction (49%) of NOBOB ships discharge freshwater ballast water into Lake Superior. Putative sources of recently established NIS in the Great Lakes are generally consistent with major ports (Antwerp, Rotterdam) and regions (lower Rhine, Baltic Sea) from whence much Great Lakes ship traffic originates. Although actual 'propagule pressure' cannot be quantified at present, the pattern of ballast water discharge by BOB and NOBOB vessels in the Great Lakes indicates that Lake Superior should be particularly vulnerable to ballast water-mediated invasions by NIS.

Author to Contact: Hugh MacIsaac
ph. (519) 253-3000 ext. 3754
fax (519) 971-3616
email: hughm@uwindsor.ca

SALINITY TOLERANCE OF LARVAL *RAPANA* VENOSA: IMPLICATIONS FOR DISPERSAL AND ESTABLISHMENT RANGE ON THE U.S. EAST COAST

Roger Mann and Juliana M. Harding, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA

Key Words: *Rapana venosa*, salinity, temperature, dispersal, establishment

The lack of quantitative data on environmental tolerances of early life history stages hinders estimation of both dispersal rates and establishment ranges for invading species in receptor environments. This is particularly evident in consideration of invading species with pelagic larval life history phases where the pelagic stage effects most if not all of the dispersal at the time frame of a single generation. We present salinity tolerance data for all stages of the ontogenetic larval development of the invading predatory gastropod *Rapana venosa*. We propose that salinity tolerance is the dominant response controlling potential dispersal (= invasion) range of the species into the estuaries of the Atlantic coast of the United States. Salinity tolerance is then examined in conjunction with temperature, which dictates both periodicity of adult egg laying and larval development rate, and extant nearshore and estuarine current data, to estimate rates of dispersal and range expansion from the current invading epicenter in the southern Chesapeake Bay. All larval stages exhibit 48 hr tolerance to salinities as low as 15 ppt with minimal mortality. Below this value survival grades to no survival at less than 10 ppt. This tolerance is greater than of the adults of the large native predatory gastropods of the genera Busycon and Busycotypus with which, we predict, *Rapana* will compete directly for space and prey, notably infaunal pelecypods. We predict that counter clockwise, gyre-like circulation within the Chesapeake Bay will initially distribute larvae northward along the bay side of the DelMarVa peninsula, and eventually to the lower sections of all the major subestuaries of the western shore of the bay. The discovery in summer 2000 of small (80 mm as opposed to adult specimens of >160 mm maximum dimension) *Rapana* at the along the northerly leg of this gyre adds weight to the predicted dispersal route. Dispersal onto and along the coastal shelf outside of the bay mouth may be influenced by both northward and southward flowing residual current depending on depth, wind conditions, and time within the known egg laying period of the invader in the southern Chesapeake Bay. Establishment over a period of decades from Cape Cod to Cape Hatteras by natural dispersal is considered a high probability. This time frame may, however, be considerably reduced by passive dispersal of larval forms in ballast water during intra-coastal maritime trade.

Author to Contact: Dr. Roger Mann
School of Marine Science
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062
Tel 804/684-7360
FAX 804/684-7045
e-mail: rmann@vims.edu

INVESTIGATIONS INTO BALLAST WATER EXCHANGE IN EUROPEAN REGIONAL SEAS

Tracy McCollin, Elspeth Macdonald, John Dunn, Christopher Hall and Suzanne Ware

Fisheries Research Services Marine Laboratory Aberdeen

Key Words: Exchange efficiency, regional seas, ballast water management.

In order to reduce the introduction of non-indigenous or potentially harmful organisms transported in ballast water the Marine Environment Protection Committee (MEPC) of the International Maritime Organisation (IMO) is currently drafting ballast water management guidelines. However, at present there is no single treatment option or management method for aquatic organisms in ships' ballast water that is completely effective, operationally and environmentally acceptable and safe for the vessel and her crew. Work towards international regulation for ships' ballast water is currently based on ships exchanging their ballast water whilst on "deep sea" voyages. To date, the majority of scientific studies of ballast water exchange have involved vessels on trans-oceanic voyages. There has been less research into whether this method may be suitable within European waters where the majority of the shipping activity tends to be regional (Macdonald and Davidson, 1997; McCollin et al., 1999). Owing to the lack of alternative ballast management methods, it is possible that ballast exchange may be utilised as a management method in regional seas. Further research is required to determine whether ballast water exchange in regional seas is an effective method of reducing the number of organisms transported in ballast water.

Preliminary studies carried out by Macdonald and Davidson (1998) indicated that ballast water exchange in the North Sea and Irish Sea might be less effective at reducing the diversity and abundance of phytoplankton. Mid-water exchange increased the diversity of diatoms and dinoflagellates in 69% and 85 % of cases respectively and abundance increased in 31% and 85% of cases. Although this initial study suggested that exchange might not be as effective in regional waters it is a management option that requires further study. It may be possible to identify a seasonal or spatial effect where the effects of exchange may vary according to the time of year or the exchange area. If there is to be a requirement for in-transit exchange of ballast water in regional seas then it is important that these effects are better understood. For these reasons a three year project is underway at the FRS Marine Laboratory in Aberdeen that aims to:

· Carry out a detailed assessment of the efficiency of in-transit exchange in the North Sea and Irish Sea on planktonic organisms in ships' ballast tanks.
· Assess the survival of planktonic organisms whilst on passage in ballast tanks.

The project is being carried out in collaboration with a shipping company that uses bulk carrier vessels to transport aggregate from the west coast of Scotland to ports within northern Europe. The vessels return to Scotland in ballast and routinely carry out ballast exchange on the return trip. Research staff join the vessel at ports in Northern Europe and accompany the vessel back to Scotland. Samples are collected during the voyage from both the ballast tanks and from the water in which the exchange is taking place as follows:

· Water samples are collected from the ballast tanks before, during and after exchange for phytoplankton, zooplankton and salinity analysis.
· Part of the water pumped on board during the exchange process is diverted through sensors and a data logger to measure the temperature, salinity, conductivity, transmittance and fluorescence of the water before it enters the ballast tanks.
· A towed instrument (U-Tow) is deployed just prior to ballast water exchange and retrieved just after, and is programmed to take phytoplankton and zooplankton samples at pre-set intervals.
· Data from the vessel's Geographical Positioning System (GPS) is used to record the location of the vessel during exchange and this is merged with the data from the data logger to allow generation of detailed analysis of the hydrographic condition throughout the ballast exchange process.

The project commenced in 1999 with the current emphasis on undertaking cruises over a seasonal cycle. To date, eight cruises from six different European ports have been successfully completed and further cruises are planned from other origin ports. The cruises have included return journeys via both the North Sea and

the Irish Sea and the exchange process has been undertaken in different areas of the English Channel, Irish Sea and North Sea. Both the flow through and empty-refill methods of exchange have been carried out on different cruises.

Efforts are made to collect samples from all fourteen topside ballast tanks in order to allow comparisons of plankton numbers and diversity within and between both tanks and cruises. The number of samples collected depends on a number of factors, for example, the type of exchange process carried out and the length of the trip. Plankton samples are currently being analysed and a dedicated database is being developed to store the data. This information, along with the data from the GPS and environmental logging systems, will be used to assess the efficiency of ballast water exchange within regional seas. To date, statistical analysis carried out on zooplankton samples from one cruise suggested that abundance did not significantly change after exchange but diversity increased following exchange. Samples from other cruises will be analysed to further assess how abundance and diversity are affected by ballast exchange. Phytoplankton analysis is being carried out to obtain quantitative taxonomic data for all samples from five cruises. This will allow statistical analysis to determine whether there are significant differences in number of taxa between tanks, side of vessel and before and after exchange. Initial analysis on samples from one cruise suggests that there were some differences in the number of taxa between tanks and in the number of taxa before and after exchange.

In the longer term, it is hoped that results from this work will aid the development of future national and international ballast water management, particularly with respect to the regional nature of European shipping.

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Author to Contact: Tracy McCollin
FRS Marine Laboratory
P.O. Box 101, Victoria Road, Aberdeen, AB11 9DB.
Tel: ++ 44 (0) 1244 876544
Fax: ++ 44 (0) 1244 295511
E-mail: mccollint@marlab.ac.uk

POSSIBLE BIOLOGICAL CONSTRAINTS ON SPATIAL DISTRIBUTION AND ABUNDANCE OF THE NONINDIGENOUS GREEN CRAB *CARCINUS MAENAS* (L.) ON THE WEST COAST OF NORTH AMERICA

P. Sean McDonald[1], Gregory C. Jensen[1], Liz Carr[2], Brett R. Dumbauld[2], and David A. Armstrong[1]

[1]School of Aquatic and Fishery Sciences, University of Washington, Seattle
[2]Willapa Bay Field Station, Washington Department of Fish and Wildlife, Nahcotta, WA

Key Words: *Carcinus maenas*; *Cancer* spp.; Green crab; habitat; limb damage

The European green crab, *Carcinus maenas*, has a long history as an invasive colonizer worldwide. Although native to temperate waters of the eastern Atlantic, it has established reproducing populations in the western Atlantic, South Africa, Tasmania, Japan, and the northeastern Pacific (reviewed in Cohen et al., 1995). The success of *C. maenas* as an invader is due in large part to its broad ecological tolerances. *C. maenas* is a euryhaline species, and occupies diverse habitats throughout its native and introduced range, including shallow embayments, estuaries, and intertidal rocky shores. It is also common subtidally to 6 m in many areas, and populations often migrate into shallow water with the rising tide to forage.
In contrast to other areas of its range, populations of *C. maenas* along the west coast of North America are restricted to low-energy, soft-bottom habitats. It is often found on mud or sand and is typically associated with epibenthic structure. However, preliminary observations have suggested that within these habitats the species exhibits a patchy distribution and may even be concentrated in marginally suitable areas. In order to determine patterns of habitat use and investigate potential constraints on the spatial distribution of adult C. maenas, we conducted intertidal trapping surveys in Bodega Bay harbor, California, and Willapa Bay and Grays Harbor, Washington. Extensive subtidal trawl surveys were also done within both Washington State estuaries.

Survey results from Bodega Bay Harbor show a strong negative relationship between the abundance of *C. maenas* and the large native crabs *Cancer productus* and *C. antennarius*, and *C. maenas* is largely absent from areas of suitable intertidal habitat occupied by these species. Specimens of *C. maenas* collected from various areas within Bodega Bay Harbor also differed markedly in their relative condition. Those collected from an isolated marsh area showed low levels of limb damage comparable to that reported by McVean and Findlay (1979) for a European population. Conversely, the incidence of missing limbs was nearly three times greater in areas where the distribution of *C. maenas* overlaps with native *Cancer* spp. These larger crabs move into the intertidal to forage during nighttime high tides, and may be preying upon and displacing *C. maenas*.

A similar pattern of distribution was observed in surveys of Willapa Bay and Grays Harbor. In these estuaries, *C. maenas* was primarily found in native vegetation or dense meadows of the cordgrass *Spartina alterniflora* located in the high intertidal. These areas are far-removed from the preferred habitat of the native crab *Cancer magister*, which is abundant in subtidal channels and moves onto intertidal mudflats to feed. Furthermore, extensive small-mesh beam trawl surveys conducted annually (June and August) in both Washington State estuaries have yet to capture any *C. maenas*, which suggests that during summer months the species is not utilizing subtidal areas where *C. magister* is most abundant.
These data suggest that native Cancer spp. may restrict the distribution of *C. maenas* to marshes, high intertidal areas and low-salinity refuges in many habitats. Interactions with this guild of large crabs may have implications for the potential range of *C. maenas* in the northeastern Pacific.

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Author to contact: P. Sean McDonald
University of Washington
School of Aquatic and Fishery Sciences
Fisheries Sciences Building
Box 355020
Seattle, WA 98195, USA
Phone: (206) 221-5456
Fax: (206) 685-7471
Email: psean@u.washington.edu

Ballast Water Education and Management on the West Coast of the United States

Karen Hart McDowell and Jodi Cassell, California Sea Grant Extension Program

Key Words: ballast water, west coast, education

The California Sea Grant Extension Program started the West Coast Ballast Outreach Project in February 1999. This project is funded by the National Sea Grant College Program and the Cal-Fed Bay Delta Program. Since the program's inception, various regulations that require specific ballast water management protocols, ranging from the federal to the state level, have been passed. This project has worked together with the maritime industry, regulators, and researchers over the past two years to educate the various groups on the recent developments and to coordinate management efforts along the west coast.

The West Coast Ballast Outreach Project has sponsored a series of workshops, produced a biannual newsletter, developed a web site, and produced a poster and brochure to distribute information about the latest developments in ballast water management and information on the impacts of aquatic nuisance species. The ballast water forums were held at various locations along the west coast, and were well attended by regulators and maritime industry representatives. The three volumes of the newsletter, "Ballast Exchange," included updates on the various regulatory and research programs. The web site includes information about the project, general information on ballast water and aquatic nuisance species, and links to various ballast water and aquatic nuisance species web sites. The poster and brochure, "Stop Ballast Water Invasions," contain general information about ballast water regulations and aquatic nuisances species. These documents have been widely distributed to regulators and the maritime industry.

In addition to our educational efforts, the West Coast Ballast Outreach Project has been actively involved with several working groups, the Pacific Ballast Water Group, the Pacific Ballast Water Pilot Project, and the Ballast Outreach Advisory Team. The Pacific Ballast Water Group, established in 1998, is as ad-hoc group, made up of various stakeholders, to coordinate ballast water management activities along the west coast. The Pacific Ballast Water Pilot Project, established in 2000, is working to develop ballast water treatment standards and to test various ballast water treatment systems. The Ballast Outreach Advisory Team is made up of members representing the maritime industry, regulatory agencies, and environmental groups. We have worked closely with this team throughout this project to insure that we are providing the proper educational information needed for these groups to implement and comply with the various ballast water regulations. As a result of these cooperative efforts, awareness of the impacts of aquatic nuisance species and compliance with the various new ballast water regulations has increased along the west coast.

Author to Contact: Karen Hart McDowell
California Sea Grant Extension Program/SFEP
1515 Clay Street
Suite 1400, Oakland, CA 94612
Phone: 510-622-2398
Fax: 510-622-2501
Email: kdhart@ucdavis.edu
www.ballast-outreach-ucsgep.ucdavis.edu

EVALUATING AND DISSEMINATING INFORMATION CONCERNING THE SPREAD OF *CAULERPA TAXIFOLIA* ALONG THE FRENCH MEDITERRANEAN COASTS

MEINESZ Alexandre, COTTALORDA Jean-Michel, CHIAVERINI Danièle, THIBAUT Thierry and VAUGELAS de Jean. Laboratoire Environnement Marin Littoral
Université de Nice Sophia Antipolis

Key Words: survey, detection, communication, *Caulerpa taxifolia*

From the first finding of 1 square meter of the tropical introduced algae *Caulerpa taxifolia* (Vahl) C. Agardh to the present day situation which involves 3184 hectares of the invasive alga along the French coasts, a global strategy of detection, survey and communication of the spread has been implemented.

The first step is a detection of the alga's presence. It became quickly apparent that the alga covered a large region (in 1990 a colony was found 200 km west from the first spot). Since then, the detection and assessment of the spread can no longer be carried out by scientists or other local administrations. It was thus necessary to set up a public awareness campaign with two main objectives:
- to inform proper the authorities of the presence of the alga
- to avoid disseminating the alga by way of boat anchors

To this end, frequent public awareness campaigns have been carried out since 1991. These have allowed us to detect 80% of the newly colonized zones (Cottalorda et al 1998). Each reported colonized zone is checked by scientifically-trained SCUBA divers able to recognize the alga. In order to follow the evolution of older and more extensive colonized zones, transects were performed annually using a towed video camera (Belsher 1992).

The second step is a global evaluation of the spread. Each colonized zone is very different, and depends on the lapse of time since initial settlement. All of the intermediate situations can be observed, from a single isolated and small colony of 1 square meter to a large infested zone covering 15 km of coastline and present between depths of 0 to over 50 m. Each algal colony develops quickly, which necessitates a regular monitoring of the situation. In light of the increasing difficulty in both controlling the situation and performing the surveys, a standardization of the monitoring protocol was proposed (Vaugelas et al. 1999). This standardized protocol allows the situation to be assessed based on well defined descriptive criteria that are adapted to both the nature of the colonized zone and the monitoring efforts to be undertaken. This standardization is based on three levels of invasion that correspond to three means of evaluating the surface areas and length of coastline concerned by the invasive algal spread. Using this standardization of the descriptive criteria, any changes in the situation are easily described and can be compared from one year to the next.

The last step concerns the communication of the information. From the onset of this problem, efforts have been made to group all information concerning the spread of this alga. Between 1984 and 1991, the number of colonies increased dramatically. In order to keep both the concerned authorities and sea-going persons informed, we published an annual report from 1991 to 1998 that identified all of the invaded zones. In addition, a report was drawn up for each newly discovered zone and sent to the government and local authorities. By the end of the year 2000, over 90 zones were concerned by the invasion. In order to render more accessible this information and to avoid a tedious updating of the invasion information, an Internet data bank has been created (http://www.unice.fr/LEML), which has been called COL (Caulerpa on Line). At present, all persons interested and concerned by this problem can access this data bank, in which each colonized zone is described and a overview of its spread and corresponding maps are provided.

These three steps allow a better and more efficient understanding of the evolution of *Caulerpa taxifolia* spread, a phenomenon that has persisted along the French Mediterranean coasts since 1984.

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Author to contact: Prof. A. MEINESZ,
Laboratoire Environnement Marin Littoral
Université de Nice Sophia Antipolis
06108 Nice Cedex 2
France
e-mail: meinesz@unice.fr
tel: 33 4 92 07 68 46
fax: 33 4 92 07 68 49

TRANSFERRING SEA GRANT AQUATIC NUISANCE SPECIES RESEARCH AND OUTREACH RESULTS TO THE NATION USING A WORLD WIDE WEB SERVER (SGNIS)

Brian K. Miller

Assistant Director, Illinois-Indiana Sea Grant, Purdue University

Key words: Nonindigenous species, aquatic nuisance species, www, outreach

Congressional action in response to the invasion of zebra mussels and other aquatic nuisance species in the Great Lakes led to the passage of the Non-indigenous Species Control Act of 1990 and resulted in over $17 million being spent by Sea Grant on research and outreach projects. The growing wealth of information resulting from these projects is of high value as aquatic nuisance species move to other regions of the country. The work of the Sea Grant programs can help others to respond more rapidly by applying research findings to control strategies and by using the richness of the educational materials available to teach industry and resource management agencies. This is one of the few genuinely peer-reviewed sites on the web. Great care has been taken to ensure that all materials are of the highest quality and to make sure that all information is searchable and easily accessible to the end user. This site exemplifies how technology will be transferred in the future. Researchers and other users can conduct a literature search (as is done on searchable library databases) and in addition can download the entire document or product on demand. This moves the transfer of scientific technology one step further and makes application and use of scientific information quicker and easier.

The SGNIS web site contains high-quality science and has been the web presence for the National Sea Grant College Program on non-indigenous issues since 1996. All documents contained on the site, both research and outreach, have bee subjected to peer review. People who use the site can be confident that the available materials are of the highest quality. To date, the SGNIS database contains over 1100 research reports and educational items. Currently housed at the site are over 428 completed research findings, 40 ongoing research abstracts, 312 research and outreach papers in six conference proceedings, 85 issues of newsletters, a 70 slide graphic library, 53 general publications, 14 training materials and three distribution maps. Contributions to SGNIS have been made by over 100 organizations (20 of which are Sea Grant Programs) and 23 peer reviewed journals. Last year SGNIS was accessed by users in 83 countries from government, universities, and industries.

In 2000, a panel of Sea Grant outreach leaders and national office representatives were engaged to develop a seamless interface by pulling all national Sea Grant ANS web sites into a national web. Future additions to the site include: 1) adding materials for additional Aquatic Nuisance Species, 2) enhancing and expanding an interactive kids section, 3) adding appropriate gray literature to the site in topic areas where peer reviewed literature is not available.

Author to contact: Brian K. Miller, Assistant Director
Illinois-Indiana Sea Grant, Purdue University
1200 Forest Products Bldg. West Lafayette IN 47907-1200
Phone (765) 494-3586
Fax (765) 496-6026
Email: bmiller@fnr.purdue.edu

DIRECT EFFECT OF A NONINDIGENOUS CICHLID (*CICHLASOMA CYANOGUTTATUM*) ON REPRODUCTIVE SUCCESS OF NATIVE CYPRINODON

June B. Mire, Ph.D.
Department of Biological Sciences
University of New Orleans
New Orleans, Louisiana Stacey Byers
McGill School of Environment
McGill University
Montreal, Quebec, Canada.

Keywords: nonindigenous, fish, direct effect, reproduction, cichlid

The Rio Grande cichlid (*Cichlasoma cyanoguttatum*) was introduced into drainage canals in the New Orleans area in the early 1990s, and has since spread throughout the canal system south of Lake Pontchartrain. Native to northeastern Mexico and the lower Rio Grande, this cichlid can tolerate low temperature and dissolved oxygen, as well as high salinity. Although the invasive nature of the Rio Grande cichlid is well documented, and circumstantial evidence suggests it displaced native fishes in the canals, little is known about the direct effects of the cichlid on any native fishes. We compared the reproductive success of the native *Cyprinodon variegatus* in the presence and absence of young of the year Rio Grande cichlids. Four female and three male adult Cyprinodon were placed in 10 pools outdoors and allowed to spawn freely. Nine young of the year Rio Grande cichlids were added to half of the pools. Fish were matched for size among controls and treatments. After 6 weeks, all fish were recovered and preserved. Adult Cyprinodon and all cichlids were measured, and Cyprinodon fry were counted. A strong direct negative effect of the cichlid on reproductive success of Cyprinodon was shown. None of the 5 treatment pools yielded fry. Follow-up experiments will also be discussed.

Author to contact: June B. Mire, Ph.D.
6813 Louisville Street
New Orleans, Louisiana 70124
(504) 486-3883
Email: tucker9@bellsouth.net

A FRAMEWORK FRO EMPIRICAL RESEARCH ON ALIEN SPECIES

Kate Murphy and Greg Ruiz

Smithsonian Environmental Research Center

Key Words: ballast water, exchange, verification

A primary vector for the movement of aquatic organisms within and between oceans is ships' ballast water. Although there are no systems in use today that will prevent the introduction of aquatic nuisance species (ANS) with ballast water, the International Maritime Organization (IMO) established voluntary guidelines aimed at minimizing such introductions. The primary method for reducing the risk of the introduction of nonindigenous species into U.S coastal water is for ships to perform mid-ocean ballast water exchange (BWE). During exchange, a vessel replaces its original ballast water (taken on board while the vessel was in port or near to the coast) with water from the open ocean. Ballast exchange reduces ANS by 1) discharging a percentage of them into the inhospitable environment of the ocean, and in some cases, 2) by increasing the salinity level within the ballast tank to a level such that the species of freshwater or brackish water origins cannot survive.

On May 10, 1993, the U.S. Coast Guard's ballast water management regulations became effective for vessels traveling to the Great Lakes that operate beyond the Canadian or the United States exclusive economic zone (EEZ). These regulations mandate BWE as the current procedure to control the introduction of nonindigenous species. Exchange is to take place in water outside the 200 mile EEZ and in depths greater than 2000 meters.

On October 26, 1996, Congress enacted the National Invasive Species Act of 1996 (NISA) (Pub. L. 104-332), which amended and reauthorized NANPCA. NISA provides for ballast water management to prevent introductions and spread of ANS. It expands the scope of Coast Guard regulations to include all waters of the United States.

In compliance with NISA, the Coast Guard regulatory guidelines become mandatory after three years unless the maritime industry shows a high rate of compliance under a self-policing system. Therefore, the interim rule establishes a ballast management reporting provision, which will assist the Coast Guard in assessing compliance for the next two years. Salinity measurements are currently used by the US Coast Guard to verify ballast water exchange. In some cases, the presence of low salinity ballast water (< 30 ppt) is sufficient to show that the water was not exchanged in mid-ocean, however, the technique fails when the source of the ballast is a high-salinity coastal port. In these situations, it is necessary to identify more refined techniques to determine the origin of the ballast water.

To address this problem, the Smithsonian Environmental Research Center (SERC) in conjunction with the United States Coast Guard (USCG) intiated a program to investigate whether a suite of characteristics (chemical, biological, physical or a combination of these) can be used to discriminate between coastal and oceanic water and as such represent reliable indicators of exchange, regardless of the salinity of the coastal source water.

A workshop was held at SERC in August 2000 to discuss potential techniques for verifying BWE. The workshop was attended by representatives from SERC and the USCG as well as a panel of nine invited experts. The expert panel consisted of chemical and biological oceanographers who presented information upon, and evaluated a diverse range of, potential verification techniques. Of these, it was decided that DOM fluorescence, trace metals, turbidity, lignin, radium and phytoplankton as well as the "Newcastle" verification method demonstrated the most promise as verification tools and were worthy of further investigation in this context.

To provide data on the suitability of each of these techniques for verifying BWE, ballast water samples were collected from two vessels during voyages to Alaska in November and December 2000. The first vessel left out of San Francisco with ballast tanks containing low-salinity coastal water; the second left out of Los Angeles with coastal water barely distinguishable in terms of salinity from the surrounding ocean. Each vessel performed a 300% flow through exchange in one tank, while keeping the 'partner' tank as an unexchanged control. The first vessel performed an additional 100% empty refill exchange on a third tank. Ballast water samples were collected and insitu measurements performed before and after the exchanges with mid-ocean water took place. Samples were sent to various specialist US laboratories for analysis. In

this presentation, we discuss some intial results of the two ballast water exchange verification experiments, and future directions for this program.

Author to Contact: Kate Murphy
Smithsonian Environmental Research Center
647 Contees Wharf Rd, Edgewater, MD 21037
Tel: 443 482 2361
Fax: 443 482 2380

THE ASIAN SHORE CRAB *HEMIGRAPSUS SANGUINEUS* IN NEW ENGLAND: CHANGES IN RESIDENT CRAB POPULATIONS?

Nancy J. O'Connor

University of Massachusetts Dartmouth

Key Words: Asian shore crab, *Hemigrapsus sanguineus*, *Carcinus maenas*, mud crabs, population ecology

Documenting ecosystem changes resulting from the establishment of biological invaders requires an understanding of the system before, during, and after colonization of the invader. Biological invasions that are currently in progress provide the best opportunity for this type of assessment. However, such comparative data exist for few species.

The Asian shore crab *Hemigrapsus sanguineus* is currently becoming established along the rocky intertidal coastline of New England. First noticed in New Jersey in 1988 (McDermott 1991), the crab was well established in southern New England by 1996 (Lohrer and Whitlatch 1997, Ledesma and O'Connor in press). Currently, the species' range extends to New Hampshire (McDermott, pers. comm.), with populations along the Massachusetts coastline continuing to grow in size.

H. sanguineus occurs throughout the rocky intertidal zone, reaching maximum densities in the mid to lower intertidal zone. Resident crab species, such as green crabs (*Carcinus maenas*, which is also non-indigenous), mud crabs in the family Xanthidae, and rock crabs (*Cancer* spp.) also inhabit the lower rocky intertidal zone. The objective of the study was to determine whether populations of these crabs are affected as *H. sanguineus* becomes established. Specifically, I asked whether densities of other crab species tend to decrease as densities of *H. sanguineus* increase.

Crab populations in several localities were sampled repeatedly, usually in the spring (May to early June) and fall (September to October) to examine temporal changes in crab populations and to determine whether any changes observed were similar at different locations. Sites sampled include Bristol, Rhode Island, in Narragansett Bay, and several sites along the Massachusetts coast: Washburn Island, Falmouth, in Vineyard Sound; Bourne, near the east end of the Cape Cod Canal; Sandwich and Dennis in Cape Cod Bay; and Marshfield and Scituate on the shore south of Boston. Three to five replicate 2m2 square quadrats were randomly placed on rocky (= 75% rock cover) areas low in the intertidal zone during low tide. All crabs were removed from the quadrats, identified, counted, measured in most cases, and then returned to the sampling site. Sampling began in 1996 at Sandwich and Washburn Island, and from 1997-1999 at the other locations.

The most abundant species at the sites were xanthid crabs, *C. maenas*, and *H. sanguineus*. *Cancer* spp., when present, usually occurred in very low densities (< 1 crab/m2). During initial sampling in Bristol and Washburn Island, xanthids were the most abundant and *H. sanguineus* occurred at low densities (< 5/m2). However, within two years the dominance pattern switched, with *H. sanguineus* reaching densities of 30-50/m2 and xanthids falling to < 2/m2. At Sandwich and Bourne, *H. sanguineus* abundance increased over 2-4 years, reaching densities of 76/m2 in Sandwich and 120/m2 in Bourne by fall 2000. *C. maenas* densities remained low (< 10/m2). At Dennis, *C. maenas* was the most abundant species in fall of 1997, although its density was low (5/m2). By fall of 1998, *H. sanguineus* became (and remained) the most abundant species, with densities fluctuating around 15/m2. North of Cape Cod, in Marshfield and Scituate, *C. maenas* remained the dominant crab species. However, *C. maenas* densities declined in Marshfield between 1999 and 2000 whereas *H. sanguineus* densities increased. Sampling planned in 2001 should determine whether this trend continues.

Size-frequency distributions of *C. maenas* and *H. sanguineus* showed temporal patterns. For both species, especially *C. maenas*, the populations were dominated by small crabs (< 8 mm carapace width) in the fall, indicating a recent recruitment period. *H. sanguineus* populations also contained several small crabs in May-early June, suggesting a spring as well as late summer-fall period of recruitment.

In summary, the establishment of *H. sanguineus* has negatively affected the abundance of xanthid crabs, although the mechanism is unknown. *H. sanguineus* might be impacting *C. maenas*, because densities are low where *H. sanguineus* is abundant. However, future sampling at Scituate and Marshfield, where *C. maenas* currently dominates, is necessary to determine whether *C. maenas* densities will decline if *H. sanguineus* populations grow in size.

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Author to Contact: Nancy J. O'Connor
Department of Biology and School for Marine Science and Technology
University of Massachusetts Dartmouth
285 Old Westport Road
N. Dartmouth, MA 02747-2300, USA
Tel: 508-999-8217
Fax: 508-999-8196
Email: noconnor@umassd.edu

SALINITY TOLERANCE OF LARVAL *RAPANA VENOSA*: IMPLICATIONS FOR DISPERSAL AND ESTABLISHMENT RANGE ON THE U.S. EAST COAST

Charles R. O'Neill, Jr.

Senior Extension Associate, New York Sea Grant

The lack of quantitative data on environmental tolerances of early life history stages hinders estimation of both dispersal rates and establishment ranges for invading species in receptor environments. This is particularly evident in consideration of invading species with pelagic larval life history phases where the pelagic stage effects most if not all of the dispersal at the time frame of a single generation. We present salinity tolerance data for all stages of the ontogenetic larval development of the invading predatory gastropod *Rapana venosa*. We propose that salinity tolerance is the dominant response controlling potential dispersal (= invasion) range of the species into the estuaries of the Atlantic coast of the United States. Salinity tolerance is then examined in conjunction with temperature, which dictates both periodicity of adult egg laying and larval development rate, and extant nearshore and estuarine current data, to estimate rates of dispersal and range expansion from the current invading epicenter in the southern Chesapeake Bay. All larval stages exhibit 48 hr tolerance to salinities as low as 15 ppt with minimal mortality. Below this value survival grades to no survival at less than 10 ppt. This tolerance is greater than of the adults of the large native predatory gastropods of the genera Busycon and Busycotypus with which, we predict, *Rapana* will compete directly for space and prey, notably infaunal pelecypods. We predict that counter clockwise, gyre-like circulation within the Chesapeake Bay will initially distribute larvae northward along the bay side of the DelMarVa peninsula, and eventually to the lower sections of all the major subestuaries of the western shore of the bay. The discovery in summer 2000 of small (80 mm as opposed to adult specimens of >160 mm maximum dimension) Rapana at the along the northerly leg of this gyre adds weight to the predicted dispersal route. Dispersal onto and along the coastal shelf outside of the bay mouth may be influenced by both northward and southward flowing residual current depending on depth, wind conditions, and time within the known egg laying period of the invader in the southern Chesapeake Bay. Establishment over a period of decades from Cape Cod to Cape Hatteras by natural dispersal is considered a high probability. This time frame may, however, be considerably reduced by passive dispersal of larval forms in ballast water during intra-coastal maritime trade.

Author to Contact: Charles R. O'Neill, Jr.
Senior Extension Associate, New York Sea Grant
Director, National Aquatic Nuisance Species Clearinghouse
Morgan II, State University College
Brockport, NY 14420
Phone: (716) 395-2638 Fax: (716) 395-2466
E-mail: cro4@cornell.edu

MODELING THE EVOLUTIONARY CONSEQUENCES OF SPECIES INVASIONS: CAN NATIVE PREY ADAPT IN TIME TO AVOID EXTINCTION?

Deborah Pakes -University of Guelph (Graduate student)
Elizabeth Boulding -University of Guelph

Key Words: predator invasions, rapid adaptation, marine ecology, gene flow, evolution

Ecological effects of invading predatory species, such as crowding competition and displacement of native organisms have been well studied and are known to be important both economically and ecologically. Evolutionary effects of invasive predators such as causing life history changes or extinctions are less well known. Endemic prey species may not be able to evolve defenses against specialized predator and will go extinct unless they can quickly adapt. Rapid adaptation due to predators has been shown to cause changes in life history traits as quickly as 18 generations in experiments with guppies (Resnick 1997). In field experiments that have dealt with predator prey interactions, removal experiments are more common than introductions (Sih et al 1985). This work entails the addition of predatory shore crabs (*Hemigrapsis nudus*) to wave exposed rocky intertidal shores where they do not naturally inhabit by building shelters for them. We are in the process of developing techniques to monitor demographic and population parameters to predict whether local snail populations (*Littorina* sp.) will go extinct after the invasion using a model developed by Boulding and Hay (in review). These shore crabs have been found to selectively prey on thinner shelled snails, and forage mainly within 3 meters of their shelters. After adding crabs to selected field sites we can monitor the parameters needed for the model which include: prey population size, prey population growth rate, heritability of a quantitative trait under selection (shell thickness), phenotypic variance of that trait, the strength of selection by the predator, and gene flow from neighboring prey populations subject to different selection pressures. The present research focuses on development of techniques to measure the later two parameters in order to be able to manipulate the system and monitor the evolutionary changes in the prey after the additions of predators. We have found that the strength of selection is dependant on the predator size and needs to be measured separately for each invading size class in order to get an accurate idea of the intensity of selection pressure. The large crabs are less selective on shell thickness than the small crabs. Using this information we can also manipulate the selection pressure experimentally by adding large or small crabs to various sites. We have also found that the snail neighborhood size is roughly the same area as the crabs foraging range (about 3 meters). We are unsure as to whether migration from other snail populations experiencing different selection pressure is a constraint to local adaptation. Future experiments, now that all parameters are measurable, will focus on this aspect and will attempt to highlight which parameters are most important in determining whether local native populations will adapt or go extinct after the invasion of an exotic predator. This work will allow the testing of current models in predicting the evolutionary effects of invading organisms in the intertidal as well as other ecosystems subject to invasions, which are becoming more common because of human activity.

Author to contact: Deborah Pakes -University of Guelph (Graduate student)
Elizabeth Boulding -University of Guelph
Presenter/contact
Deborah Pakes
Departement of Zoology
University of Guelph
N1G 2W1
Fax: 519 -767-1656

FACTORS INFLUENCING THE DISTRIBUTION AND ABUNDANCE OF THE EXOTIC SEA STAR *ASTERIAS AMUNRENSIS* DURING THE EARLY PHASE OF ITS ESTABLISHMENT IN PORT PHILLIP BAY, SOUTHERN CALIFORNIA

Gregory D. Parry and Brian F. Cohen

Key Words*: Asterias*, early invasion, spread, control

The establishment of the exotic northern Pacific seastar Asterias amurensis in Tasmania attracted a great deal of publicity and significantly increased awareness of the impact of exotic marine species throughout. Australia. During the 1990s *A. amurensis* became the most conspicuous organism in the Derwent estuary and by 1995 its population was approximately 28 million (Grannum et al. 1996). Field studies in the Derwent confirmed that *A. amurensis* preyed on a wide range of native fauna and that densities were as high as 24/m2. Consequently *A. amurensis* was considered to have the potential to profoundly affect native communities in southern Australia (Ross and Johnson 1998).

Asterias amurensis is native to the coasts of Japan and southeastern Russia. During the mid 1990s *A. amurensis* was confined to the Derwent estuary and hydrological modelling suggested that this limited distribution was the result of limited larval dispersal (Bruce 1998). However the distribution of *A. amurensis* in Tasmania still has not extended significantly beyond the Derwent estuary and more recent modelling (C. Johnson, Univ Tasmania, pers comm) suggests that most larvae are flushed from the estuary, and hence biological factors may be limiting the spread of *A. amurensis*. Between 1995 and 1997 four adult *A. amurensis* were collected in Port Phillip Bay and in early 1998 many juveniles were found (Parry et al. 2000). Studies of population genetics indicates that the Port Phillip Bay population probably came from the population in the Derwent (Murphy and Evans 1998). These two populations are 700 km apart and no *A. amurensis* have been found at intermediate locations. This distribution pattern and the prevailing currents (Bruce 1998) suggest that natural dispersal of larvae from the Derwent to Port Phillip Bay is very unlikely. Vessels travelling between Hobart and Melbourne are the most likely vector, but it is uncertain whether *A. amurensis* were introduced as larvae in ballast water or adults. That the first four animals were found 10s of km apart and all were adults spawned in at least two different years (Parry et al. 2000) suggests that these first arrivals were transported as adults. In contrast, when juveniles were first found in early 1998, many individuals of the same age were found in the same region. Such a distribution pattern would be expected if these seastars resulted from larval settlement following a successful spawning in the bay, or possibly following the discharge of ballast water containing a high density of *A. amurensis* larvae.

Most studies of exotic species do not commence until a population is well enough established to present an economic or environmental problem. Typically this occurs once the exotic species is well established, some years after the initial invasion. Studies in the Derwent followed this typical pattern and did not commence until *A. amurensis* had been established for approximately a decade (Byrne et al. 1997). However the presence of *A. amurensis* in the Derwent and its apparent impact there (McLoughlin and Thresher 1994) heightened awareness of the risk of its translocation to Port Phillip Bay and resulted in the commencement of ecological studies of *A. amurensis* in the Bay during the early phase of its establishment.

Studies during the early phase of the invasion are critical to provide a baseline against which impacts may be measured. But it appears to be less well appreciated that some insights into means of controlling pest species may only be evident during the early phase of an invasion. Factors that control the distribution and abundance of pest species may change irreversibly as the pest becomes more abundant.

This study documents changes in the distribution and population dynamics of *Asterias amurensis* during the early phase of an invasion. The population of *A. amurensis* in Port Phillip Bay has grown from 300,000 in 1998 to 30 million in 1999 to approximately 100 million in 2000. The mortality rate of seastars during their first three years in Port Phillip Bay has remained very low in the main area of infestation, but annual somatic growth has declined so that changes in seastar diameter decreased from 15 cm/year in 1998 to 8 cm/year in 1999. In 2000 the reproductive output in the main area of the infestation is only one third of

that during 1999. Growth in the main area of infestation appears density dependent. The distribution of *A. amurensis* in Port Phillip Bay has been influenced strongly by hydrodynamic factors. Hydrodynamic models suggest that limited larval dispersal explains the absence of *A. amu*rensis from western Port Phillip Bay in the period 1997-2000. However native predators may be limiting the spread of *A. amurensis* into southern regions and shallow regions on the east of the Bay.

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Author to contact: Gregory D. Parry* and Brian F. Cohen
Marine and Freshwater Resources Institute
PO Box 114
Queenscliff 3225
Phone 0011 63 5258 0334 Fax 0011 63 5258 0270.
email: greg.parry@nre.vic.gov.au

RAPID ASSESSMENT SURVEY OF NONINDIGENOUS SPECIES IN COASTAL MASSACHUSETTS

Judith Pederson[1], Robert Bullock[2], Dale Calder[3], James Carlton[4], John Chapman[5], Andrew Cohen[6], Harlan Dean[7], Peter Dyrynda[8], Larry Harris[9], Charles Lambert[10], Gretchen Lambert[10], Arthur Mathieson[9], Seth Tyler[11], and Judith Winston[12]

[1]MIT Sea Grant College Program, Cambridge, MA; [2]University of Rhode Island, Narragansett, RI; [3]Royal Ontario Museum, Toronto, Ontario, Canada, [4]Williams College-Mystic Seaport Maritime Program, Mystic, CT; [5]Oregon State University Hatfield Marine Center, Newport, OR; [6]San Francisco Estuary Institute, Richmond, CA; [7]Harvard University Museum of Comparative Zoology, Cambridge, MA; [8]University of Wales Swansea, Swansea, UK; [9]University of New Hampshire, Durham, NH; [10]Seattle, Washington; [11]University of Maine, Orono, ME; [12]Virginia Museum of Natural History, Martinsville, VA

Key Words: Southwestern Atlantic, pristine areas.

Using an approach initiated on the West Coast, a Rapid Assessment Survey of marine native and non-native species in shallow water float communities of Massachusetts was conducted from August 6-11, 2000. Twenty sites from Gloucester to Fall River, Massachusetts were visited by scientists, students and participants with broad and specific taxonomic backgrounds. The Massachusetts survey was followed by a comparable one in Rhode Island the following week with many of the same scientists participating in that survey.

Although identifications are not complete for the Massachusetts study, 157 invertebrate species and 84 algal species were identified. Of the total species identified, 20 (4 plant and 16 invertebrate) species are considered to be introduced and another 25 (1 plant and 24 invertebrate) species are classified as cryptogenic. The total number of marine nonindigenous species in Massachusetts is less than the numbers observed in Puget Sound (38 marine nonindigenous species) and San Francisco Bay (>200 marine, brackish, and freshwater nonindigenous species).

Most species are found throughout the coast of Massachusetts, but a few are limited to either north or south of Cape Cod, which divides the southern Virginian and northern Boreal Provinces.

The data and information from this study are being used to develop the marine portion of the Massachusetts Aquatic Invasive Species Management Plan. As additional information is added, a more comprehensive examination of the historical and current records of introductions will provide insight into whether more species are being introduced today compared to previous decades. As the data from Rhode Island survey become available, the information will be incorporated into a regional database that also will include the Gulf of Maine.

Author to Contact: Judith Pederson
MIT Sea Grant College Program, Cambridge, MA

FEEDING AND SUBSTRATE PREFERENCES OF THE JAPANESE SHORE CRAB, *HEMIGRAPSUS SANGUINEUS*

S.R. Percival and K. Wilson, Ph.D., Dept of Biological Sciences, CCSU

Keywords: *Hemigrapsus sanguineus*, introduced species, diet, substrate

Hemigrapsus sanguineus, the Japanese shore crab, is native to the Western Pacific Ocean and was first observed in Long Island Sound in 1992. Since then, it has become firmly established and, in many locations, is the most common crab in the rocky intertidal zone. Based on field observations, experiments were designed to determine substrate preference and aspects of the diet of the crab. Crabs were collected from Connecticut rocky shores, sexed and measured, and grouped together in three size classes (6-12mm, 13-19mm, and 20-26mm) in the lab. Experiments were conducted to determine the influence of crab sex or size on 1) preference for cobble substrate size and 2) preference for specific size ranges of the northern rock barnacle, *Semibalanus balanoides*. Individual crabs from each size class were simultaneously offered three different substrate sizes (<1cm, 2 cm, and 5 cm). In the feeding experiment, crabs were allowed to feed individually on a range of sizes of barnacles for 24 hours. Results indicate that neither sex nor carapace size of the Japanese shore crab is associated with a preference for substrate size. Most crabs preferred the five cm substrate. In the feeding experiment, neither sex nor carapace size of the crabs was associated with a preference for barnacle size. Most crabs fed on all of the barnacles.

Author to contact: Scott R. Percival
Berlin Senior High School-Science Faculty
139 Patterson Way, Berlin, CT 06037
Phone: 860-828-6577 ext. 239
Fax: 860-225-8580
email: percivalsr@aol.com

INTERJURISDICTIONAL RESPONSE TO AQUATIC NUISANCE SPECIES IN THE PACIFIC NORTHWEST

Stephen Phillips, Pacific States Marine Fisheries Commission

Key Words: ANS, mitten crab, PSMFC, outreach, Columbia River Basin

Authorized by Congress in 1947, the Pacific States Marine Fisheries Commission (PSMFC) is one of three interstate commissions dedicated to resolving fishery issues. Representing California, Oregon, Washington, Idaho, and Alaska, the PSMFC does not have regulatory or management authority; rather it serves as a forum for discussion, and works for coastwide consensus to state and federal authorities. The goals of the Portland State University Center for Lakes and Reservoirs, created in 1999, are to provide 1) education on lake and reservoir management; 2) technical assistance and management planning for aquatic nuisance species; and 3) research on aquatic nuisance species.

The PSMFC became initially involved in aquatic nuisance species (ANS) due to the arrival of Atlantic salmon (*Salmo salar*) and the Chinese mitten crab (*Eriocheir sinensis*). Atlantic salmon are grown in Washington State and British Columbia. Atlantic salmon have escaped from facilities in both the US and Canada. Some of the escaped fish have successfully spawned in British Columbia. There are concerns about disease transference between farmed and native salmonids and competitive displacement of native fish by introduced fish. The mitten crab has potential for ecological impacts on fish resources. In California, fisherman unsuccessfully petitioned the state to allow commercial harvest of mitten crab.

The mitten crab is native to estuaries and rivers along the coasts of Korea and Southern China, from the Yellow Sea to south of Shangai. In the San Francisco estuary, commercial shrimp trawlers first caught mitten crabs in 1992. The most probable mechanism of introduction to the estuary was either deliberate release to establish a fishery or accidental release via ballast water. They have spread rapidly since their introduction. Based on the impacts of mitten crabs in their native range and Europe, they pose several possible threats to the West Coast. The mitten crab is the secondary intermediate host for the Oriental lung fluke, with mammals, including humans, as the final host. Humans may become infected from eating raw or poorly cooked mitten crabs. In addition, the burrowing activity of mitten crabs may accelerate the erosion of banks and levees. In the fall of 1998, adult mitten crabs migrating downstream through the California Bay-Delta entered federal fish screen facilities interfering with juvenile salmon salvage operations. In 1997, a single Japanese mitten crab (E. japonica) was identified from the lower Columbia River near Portland, Oregon.

In 1999, the Bonneville Power Administration (BPA), recognizing the potential impact to its operations, funded the Pacific States Marine Fisheries Commission (PSMFC) and Portland State University to carry out an aquatic nuisance species (ANS) prevention program for the Columbia River Basin. The Bonneville Power Administration is primarily concerned that the westward spread of zebra mussels, another ANS, that poses a serious economic threat to the region's hydroelectric operations, and an ecological threat to native aquatic species, in particular salmon and steelhead that are listed under the Endangered Species Act. Additionally, BPA is also concerned about potential impacts of mitten crabs to the Columbia River Basin. The U.S. Fish and Wildlife Service, through the ANS Task Force, is also concerned about mitten crab and is in the process of developing a mitten crab management plan.

To address the potential threat of mitten crabs in the lower Columbia River (LCR), PSMFC and PSU are undertaking a mitten crab outreach program that includes:

1. Contacting fishing and other organizations with information about mitten crabs.

2. Undertaking presentations to organizations on the identification and threats of mitten crabs.

3. Providing mitten crab information to anglers at boat ramps throughout the LCR.

4. Distributing brochures and/or fact sheets on mitten crabs to marinas and bait and angling shops in the LCR.

5. Providing information on mitten crabs to ongoing monitoring programs in the LCR (e.g., Oregon Department of Environmental Quality EMAP water quality monitoring program).

6. Distributing mitten crabs information at venues such as festivals, boat and fishing shows.

7. Establishing mitten crab monitoring stations in the LCR.

In 2000, as a result of our outreach efforts and the posting of a mitten crab "Wanted Dead or Alive Poster," a freshwater crayfishermen reported catching a crab in the Multnomah Channel, a tributary of the Columbia River, near Portland. After interviewing the fishermen, it was determined that the crab was likely a mitten crab.

In addition to mitten crab outreach, PSMFC and PSU are involved in numerous management and decision making efforts including the Columbia River Aquatic Nonindigenous Species Initiative, Pacific Ballast Water Group, the mitten crab and Green Crab Committees of the Aquatic Nuisance Species Task Force, and the Western Regional Panel. We are also active in seeking ANS programmatic funds for Western States.

Author to Contact: Stephen Phillips
Pacific States Marine Fisheries Commission
45 SE 82nd Drive, Suite 100, Gladstone Oregon, 97207
phone 503-650-5400
fax 650 5426
Email: Stephen_Phillips@psmfc.org

GEOLOGIC AND EVOLUTIONARY UNDERPINNINGS FOR THE SUCCESS OF PONTO-CASIPAN SPECIES INVASIONS IN THE BALTIC SEA AND LAURENTIAN GREAT LAKES

D. F. Reid

NOAA Great Lakes Environmental Research Laboratory
Ann Arbor, Michigan, USA M. I. Orlova
Zoological Institute, Russian Academy of Sciences
St. Petersburg, Russia

Key Words: Ponto-Caspian, Baltic, Great Lakes, species invasion

The Caspian, Azov, and Black Seas comprise the modern Ponto-Caspian region of eastern Europe. Since 1985, about 70% of the species that have invaded the Laurentian Great Lakes are native to the fresh and brackish waters of these basins (Ricciardi and MacIsaac, 2000). The Ponto-Caspian basins are also a source of significant invasions to the Baltic Sea, with more than 20 Ponto-Caspian species now established there (Baltic Marine Biologists Working Group 30, 2000). The geologic history and faunal evolution of the Ponto-Caspian basins provide insight to understanding the success of Ponto-Caspian species in the modern Baltic Sea and Laurentian Great Lakes.

The geologic history of the modern Ponto-Caspian basins can be traced back to the mid-Miocene. Ponto-Caspian fauna evolved during this long geologic time period in a series of semi-closed and closed large lakes/seas with varying salinity ranges, water-levels, and connections to other basins. Modern fauna include many endemic species with wide tolerances to environmental changes and high phenotypic variability. In contrast, both the Baltic Sea and the Great Lakes are geologically young, with relatively low endemism. The range of environmental conditions found in the modern Ponto-Caspian and Baltic seas are well-matched to each other and also to the Great Lakes, even though the latter are entirely freshwater. The high tolerance of Ponto-Caspian fauna to varying environmental conditions and the similarity in available environmental conditions are probably major reasons why these fauna have been very successful invaders in the fresh and brackish-water ecosystems of the Baltic Sea and Laurentian Great Lakes. However, human activities that have dramatically increased the opportunities for transport and introduction have, of course, played a catalytic role.

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Author to contact: David F. Reid,
NOAA/GLERL,
2205 Commonwealth Blvd., Ann Arbor, MI 48105-2845,
(Phone) 734-741-2019,
(FAX) 734-741-2055,
(Email) reid@glerl.noaa.gov

IMPACT OF THE NORTHERN PACIFIC SEA STAR *ASTERIAS AMURENSIS* ON NATIVE MARINE COMMUNITIES IN SOUTH EAST TASMANIA

Jeff Ross[1,2]*, Craig Johnson[1], and Chad Hewitt[2]
[1]School of Zoology, and Tasmanian Aquaculture and Fisheries Institute, University of Tasmania
[2]CRIMP, CSIRO Marine Laboratories

Key Words: ballast waters, phytoplankton, survival, viability, diversity

In Australia, the introduced northern Pacific seastar (*Asterias amurensis)* has been highly conspicuous as a voracious generalist predator. It was first recorded in southeast Tasmania in 1986, where it has become the dominant invertebrate predator in the Derwent River estuary. Despite observations of seastar foraging behavior, gut contents, and feeding electivity which suggest the potential for considerable impact on native benthic marine communities, the impact of the seastar on native assemblages has not previously been examined directly or quantitatively. Because of the absence of baseline data prior to the arrival of the seastar and the presence other anthropogenic stressors in the estuary, estimating the impact of the seastar is difficult. To overcome these difficulties and the limitations of any one method of impact assessment, we used multiple methods on different scales to provide independent tests of impact: (i) experiments in which seastar density is manipulated at sites immediately beyond the current range of the seastar, (ii) experimental manipulation of seastar density following recruitment of prey, (iii) comparative analysis of prey taxa in the sediments and in seastar stomachs, and (iv) spatially hierarchical surveys to examine the relationship between infaunal assemblages and seastar abundance at several sites in SE Tasmania.. The combination of these methods provide, for the first time, a clear estimate of the impact of the seastar. In the Derwent River estuary, where the seastar occurs at high densities, live adult bivalves are rare, despite the presence in sediments of numerous remains (intact shells) of adults. Experiments conducted immediately beyond the current range clearly demonstrated a large impact of *Asterias amurensis* on adult bivalve populations. Densities of the commercial bivalves *Fulvia tenuicostata* and *Katelysia rhytiphora* were reduced from upwards of 80 per m2 and 5-7 per m2 respectively, to virtually zero per m2 in treatments with seastars. Manipulative experiments conducted in the estuary showed that *A. amurensis* could have a large impact on bivalve recruitment, effectively arresting significant recruitment events. Densities of *F. tenuicostata* recruits were reduced by ca. 15 fold in the presence of seastars at background densities relative to control treatments without seastars. These results provide strong evidence that predation by *A. amurensis* is responsible for the decline, and subsequent rarity of adult bivalves in the Derwent estuary. Observations of diet and prey switching show that while the seastar has clear food preferences, it is a generalist predator able to switch to other prey when preferred prey (bivalves) become relatively rare. Thus, *Asterias amurensis* has the potential to impact a large variety of taxa and have wider effects on soft sediment communities than demonstrated in short-term manipulative experiments. The exact nature of the effect of seastar predation on native communities in southeast Tasmania is site specific given spatial variability in soft sediment communities. We use the results from our experimental manipulations, feeding observations and results of our large-scale surveys to provide a broad synthesis of the immediate and predicted impacts on native communities, including commercial species. Our overall conclusion is that at the high densities that can occur in southeast Tasmania, there are large direct and likely indirect effects on native communities, including several commercial species. These important consequences of the arrival of this introduced predator warrant efforts to limit its impact.

Author to contact: Nathalie Simard
Fisheries and Oceans Canada
Maurice Lamontagne Institute
850 Route de la mer, Box 1000
Mont-Joli (Quebec), Canada, G5H 3Z4
Phone: (418) 775-0682
Fax: (418) 775-0718
Email: SimardN@dfo-mpo.gc.ca

BIOTIC RESISTANCE AGAINST AN INVASIVE OYSTER: IMPACTS OF NATIVE PREDATORS AND COMPETITORS

Jennifer L. Ruesink, Department of Zoology, University of Washington

Key Words: competition, experiment, growth rate, predation, survival

Both abiotic and biotic factors have been suggested to prevent invasions, restrict spread, or limit densities of invasive species. Conflicting evidence exists on the role of native species (biotic resistance), especially whether low-diversity assemblages, those that have lost native species, or those lacking particular species tend to be invasible. In this study, I examined invasion of a temperate eastern Pacific intertidal zone by the exotic oyster *Crassostrea gigas*. Potential predators and competitors were manipulated in a factorial experiment to assess biotic impacts of two guilds of native species on oyster growth and survival. To assess abiotic impacts, the experiment was set up at both wave-exposed and wave-protected sites. Concomitantly, the experiment determined strength of biotic resistance by species-rich (wave-exposed) and species-poor (wave-protected) assemblages.

Transplanted oysters were initially 4-20 mm in shell length. Individuals were followed for two months. This time period highlights early post-recruitment processes affecting invasion and was chosen because small bivalves are susceptible to stress, predation, and overgrowth. The basic experimental design was a two-factor manipulation of competitors (by removing space occupants) and predators (excluded with large-mesh cages). The experiment was repeated four times to examine seasonal and annual variation in growth and survival, as an indicator of an invasion "window" when oysters could invade. Spatial variation in invasibility was assessed by setting up the experiment at three paired sites (wave-exposed vs. protected). At wave-exposed sites, oysters were transplanted within mussel beds, and overgrowth (due to mussel leaning and movement) occurred rapidly. Competitor manipulations were carried out by removing space occupants within 10-20 cm. I did not manipulate competitors at wave-protected sites because few space occupants were present in a comparable area.

The role of wave exposure in limiting oysters was evident from treatments lacking macroscopic native species: oyster survival was 33-69% lower and growth was 44-71% lower at wave-exposed vs. protected sites. Effects of native species were of similar magnitude to these exposure-related differences. The two guilds of native species influenced oysters in different ways, predators by reducing survival (39-77%) and competitors by reducing growth (26-48%). Additionally, in two of four experiments, oyster survival more than doubled in the presence of competitors, so this guild facilitated the invasion along one life-history axis while restricting it on another. Finally, predators reduced oyster survival equivalently at wave-exposed and protected sites, despite being both more diverse and more abundant at the former. Together, these analyses suggest the importance of taxon identity in determining how native species influence invaders and indicate that biotic resistance may occur even in naturally species-poor communities.

Both spatial and temporal variation appeared in the species interactions affecting early post-settlement fates of this nonindigenous oyster. However, there was little indication of an invasion "window" when oysters might reach high cover at a particular place and time due to a fortuitous coincidence of high survival and growth. Rather, physical and biological conditions at wave-protected sites consistently allowed oysters to reach high cover, whereas nearby wave-exposed sites contained only a few scattered oysters that probably had little community-level impact.

Author to Contact: Jennifer L. Ruesink
Department of Zoology, University of Washington
Box 351800, Seattle, WA 98195-1800
T: 206-543-7095
F: 206-543-3041
E: ruesink@u.washington.edu

MANAGEMENT OF INVASIVE SPECIES TRANSPORTED IN BALLAST WATER BY DISSOLVED AIR FLOATATION TECHNOLOGY

J. Sansalone[1], E. Voon[2], V. Srinivasan[3]
[1]Civil and Environmental Engineering, Louisiana State University
[2]Civil and Environmental Engineering, Louisiana State University
[3]Department of Biological Sciences, Louisiana State University

Key Words: Ballast water, Flotation, Laser diffraction, Particle number, Unit operations

INTRODUCTION: During the twentieth century, uncontrolled discharge of ballast water has become one of the most significant transport vectors for introduction of nonindigenous invasive species (Barrett-O'Leary, 1998, Carlton, 1985). These species can survive either suspended in ballast water or find habitat in sediment deposits of vessel ballast tanks. A wide range of ballast water management strategies have been put forward to control invasive species otherwise discharged in ballast water. These strategies and technologies have produced a tool chest of potential management strategies that range from ballast water exchange at sea to physical, chemical and biological treatment techniques. One engineered technology that has shown promise as an engineered unit operation for separation of nonindigenous invasive species in ballast water is dissolved air flotation (DAF). DAF has developed as a proven technology in the wastewater treatment industry in Europe and the USA since the 1970s for particulate separation.

BACKGROUND: Flotation is the separation of suspended inorganic, biological or organic particles from a liquid phase. This separation is facilitated by the addition of a gas phase to the liquid phase, usually through the addition of air in the form of fine bubbles to the liquid phase. The rising bubbles either adhere to or are trapped in the particle structure, resulting in an increase in the buoyancy and a flotation of the bubble-particle complex. Separation by flotation depends as much on the surface properties of the particle as the size and the relative density of the particles. In the past 30 years, DAF has been successfully applied to waste treatment to remove suspended solids, grease, oil and biological solids from wastewater (Metcalf and Eddy, 1991). In dissolved-air flotation a gas phase of fine bubbles is produced from a solution supersaturated with air. These fine bubbles are achieved through saturating the liquid at high pressure and then releasing the pressure. Once the fine air bubbles are released and contact the particles suspended in water, the air-particle complex rises to the surface where it is skimmed off, and the clarified liquid is withdrawn from the bottom of the DAF system. Dissolved-air bubble sizes are smaller, ranging from 1 to 100 microns and much more numerous than in dispersed air systems. Primary design variables for DAF design are pressure; recycle ratio, influent solids concentration, water quality such as salinity, surface tension, temperature, residence time and the addition of coagulant or surfactants. Suspended biological particles and sediment characteristics of importance include particle/sediment size lnv, volume or number concentration NT, and particle specific gravity.

METHODOLOGY: A bench-scale unit operation DAF system was designed and operated to examine the efficacy of DAF for separation of biological particles and sediments from both freshwater and saltwater ballast water. The system was operated as a batch-type unit operation loaded by ballast water. Experiments were carried out for either ballast water with no salinity (less than 1 part per thousand) or ballast water with salinity between 25 and 30 parts per thousand (ppt). Clarified ballast water was introduced into a 10-L pressure vessel and placed under a pressure of 350-kPa. Ballast water containing biological particles and sediment was kept well mixed and introduced into a 152-mm diameter plexiglas column with a length of 760-mm and clarified by the introduction pressurized liquid at the base of the column. Surface loading rates were held constant and ranged from 20 to 200-L/min.-m2. Experiments were conducted for fresh and saltwater, with performance of DAF for separation of particulates and sediments examined. Analyses included turbidity, suspended solids analyses, and particle analyses utilizing laser diffraction technology. Particle indices determined were particle concentration and number-mean volume size, lnv.

RESULTS: This study evaluated performance of DAF for separation of biological particles and sediments based on examination of turbidity, suspended solids fractions and particle analyses. An example of DAF

performance based on particle analyses is presented below for freshwater and saltwater. All DAF parameters were held constant in this example except for salinity.

Figure 1. Paired plots on the left represents results of typical freshwater analyses (< 1-ppt) and the paired plots on the right (29-ppt) represent a typical saltwater ballast water analyses.

Results in Figure 1 indicate performance of DAF shows a marked improvement for saltwater as compared to freshwater. For freshwater, DAF efficiency based on particle counts, NT indicate an 80% separation efficiency while for saltwater the separation efficiency is 95%. In addition, the entire gradation for influent and effluent was modeled with a two-parameter power law function using the methods of least squares for parameter estimation. The basic form of the power law expression is given in Equation 1. Coefficient, a is an index for the particle concentration and b, while describing the slope of the particle distribution, is an index related to particle interactions.
(1)

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Author to Contact: J. Sansalone

Civil and Environmental Engineering
Louisiana State University, Baton Rouge, Louisiana, USA 70803
Ph. +225.578.6047
email: jsansal@lsu.edu

EXPERIMENTAL EVALUATION OF *RAPANA VENOSA* FEEDING RATES PREYING ON THE BIVALVE *MERCENARIA MERCENARIA* IN THE LOWER CHESAPEAKE BAY, U.S.A.

Dario Savini, Università di Pavia, Dip. Genetica e Microbiologia, Sezione di Ecologia, Pavia, Italy; Juliana M. Harding and Roger Mann, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA.

Key Words: Rapa whelk, *Rapana venosa*, *Mercenaria mercenaria*, consumption rates, Chesapeake Bay

The recent discovery of adult veined rapa whelks *Rapana venosa* (Valenciennes, 1848) in the Lower Chesapeake Bay, U.S.A. offers cause for both ecological and economic concern. Adult rapa whelks are large predatory gastropods that consume bivalves including commercially valuable species such as hard clams, *Mercenaria mercenaria*. Laboratory feeding experiments were used to evaluate daily consumption rates of two sizes of adult rapa whelks feeding on two size classes of hard clams. Empty clam shells were removed from experimental tanks and replaced with similar sized live clams daily. Hard clam shell width - tissue wet weight relationships were used to estimate the amount of flesh wet weight (g) consumed by each snail. Large rapa whelks (shell length, SL > 101 mm) are capable of consuming up to 2.7 grams of tissue daily. Smaller rapa whelks (60 - 100 mm SL) ingest in average 3.6% of their body weight every day, which is more than four times the ingestion rates of bigger *Rapana* (0.8%). Ivlev's index of preference shows that both size classes of rapa whelks preferentially consume large hard clams (shell width > 71 mm). The voracious and selective consumption of large hard clams by rapa whelks presents an economic threat to the local hard clam industry as well as an ecological threat to the Lower Chesapeake Bay in that consumption of large filter feeding bivalves affects not only hard clam stocks and reproductive potential but local benthic-pelagic coupling dynamics as well.

Author to Contact: Dr. Roger Mann
School of Marine Science, Virginia Institute of Marine Science
College of William and Mary, Gloucester Point, VA 23062
Tel 804/684-7360
FAX 804/684-7045
e-mail: rmann@vims.edu

RECENT INVADERS ALTER THE KELP BED ECOSYSTEM OFF NOVA SCOTIA

Robert Scheibling, Department of Biology, Dalhousie University

Key Words: *Codium fragile*, *Membranipora membranacea*, invasive species, alternative stable states

For many decades, the kelp bed ecosystem of Nova Scotia's Atlantic coast has exhibited cyclical alternations between two stable states, driven by large-scale fluctuations in sea urchin (*Strongylocentrotus droebachiensis*) abundance. Luxuriant kelp beds (mainly *Laminaria* spp.) covered the rocky seabed when sea urchins were rare. As sea urchin numbers increased however, they destructively grazed kelps creating "barrens" dominated by coralline red algae. The barrens stage persisted until sea urchin populations were eliminated by disease, which enabled kelps to re-establish. In recent years, synergistic interactions between two invasive species have disrupted sea urchin-kelp dynamics off Nova Scotia and shifted the rocky subtidal ecosystem to a new, apparently stable state. An epiphytic bryozoan *Membranipora membranacea*, which encrusts kelps causing tissue degradation and fragmentation, has repeatedly decimated kelp beds since the early 1990s. Widespread loss of kelp canopy has facilitated establishment of a siphonaceous green alga *Codium fragile* ssp. tomentosoides. Freed from competition with kelp, *Codium* has grown rapidly forming bushy stands that inhibit subsequent kelp recruitment and recovery. In sea urchin barrens, outbreaks of disease (caused by a waterborne amoeba, which itself may be an introduced species) released *Codium* and other macroalgae from urchin grazing pressure. Preferential fouling of kelp by *Membranipora* facilitated *Codium* during algal succession, resulting in eventual dominance by the invasive alga. Within a decade of its first appearance off Nova Scotia, *Codium* has systematically replaced kelp beds as the dominant, canopy-forming species on rocky bottoms along about 900 km of coastline. Habitat modification associated with dense "*Codium* meadows" (e.g., changes in biogenic structure, water flow, light penetration, or sedimentation rate) is expected to alter benthic assemblages of invertebrates and fish within this range. At one site near the epicenter of the *Codium* invasion, we have observed a marked increase in sedimentation, and concomitant decrease in numbers of small, cryptic and sedentary species (e.g., limpets, chitons, brittle stars), during the transition from kelp beds or barrens to *Codium* meadows. Recently established Codium meadows may persist indefinitely. Sea urchins avoid grazing *Codium* and are incapable of growth or reproduction when fed a single diet of the alga in the laboratory. Other known grazers of *Codium* (a nudibranch and several other small snails) are unable to control population growth of the alga in Nova Scotia. This large-scale community shift, mediated by a series of facilitative interactions among recently introduced species, could have significant bottom-up effects on populations of ecologically and economically important species, such as finfish, sea urchins and lobsters, that use kelps as food, habitat or nursery areas.

Author to Contact: Robert Scheibling,
Department of Biology, Dalhousie University,
Halifax, Nova Scotia, Canada
Phone: (902) 494-2296
fax: (902 494-3736
email: rescheib@is.dal.ca

EFFECT OF AN INVASIVE REEF-BUILDING SPECIES ON THE SEDIMENT DYNAMIC OF A SW ATLANTIC COASTAL LAGOON

Schwindt[1,3] E, Iribarne [1] OO, Isla [2] FI
[1]Laboratorio Ecología, FCEyN, Universidad Nacional de Mar del Plata, Argentina, [2]Centro de Geología de Costas y del Cuaternario, Universidad Nacional de Mar del Plata, Argentina,

Key Words: human disturbances, exotic reefs, ecosystem engineers, sediment dynamic.

One of the most important direct effect of non-indigenous species on communities is habitat modification, for example physically (e.g. sedimentation rate). Not only introduced species may alter the habitat but also ecosystem engineers may modulate the availability of resources to other species. The polychaete *Ficopomatus enigmaticus* (Serpulidae) is an exotic species that builds calcareous reefs distributed in brackish waters in temperate zones throughout the world and it was introduced in South America before 1943. It is considered a bioengineer organism given that it generates new refuge for other species. Reefs are efficient traps for sediments that would otherwise be transported out of the lagoon. They act as obstacles generating topographic heterogeneity, altering water flow, ameliorating environmental conditions, accumulating and stabilizing sediments. Mar Chiquita is the biggest coastal lagoon of (Argentina, (37º 32' to 37º 45' S, and 57º 19' to 57º 26' W) and receives sediment and water load from several creeks and artificial channels, the sediment transport may be caused by heavy rainfall, river drainage, floods, and human activities. Today F. enigmaticus reefs cover the 86.3% of the lagoon surface and the size of the reefs can be up to 7 m in diameter, and we hypothesized that this species has provoked a significant change in it by changing the sedimentological dynamics of the lagoon since that could retain a large portion of the sediment in the lagoon.

We evaluated the local expansion of the introduced reef-building polychaete *Ficopomatus enigmaticus* and their effect on the sediment deposition in Mar Chiquita coastal lagoon. The specifics aims were to evaluate: 1) Changes in reefs density from 1975 to 1999, 2) The effect of the reefs on sediment accumulation 3) The relationship between the reefs and grain-size distribution of the deposited sediments, 4) The effect of reefs on bedload sediment and faunal passive transport, and 5) The effect of reefs on relative water flow.

1. To evaluate changes in reef density photographs of 1975, 1979 and 1999 of the same area were compared in a covered area of 140 ha. From 1975 to 1999 the density of reefs increased from 71 reefs·ha-1 (SD = 87) to 89 reefs·ha-1 (SD = 87).
2. To evaluate the amount of sediment that accumulate the reefs, 10 reefs of similar size were transplanted to a new area during a month in the lagoon and the amount of sediment accumulated was measured as the difference between the final and initial volumes. To estimate the amount of sediment retained in the reefs in the whole lagoon we performed a bootstrapping analysis. The average of sediment accumulated was 107 kg·m-3 of reef (SD = 61). The abundance of sediment accumulated in the reefs in the lagoon was estimated in 339,3 Tn.
3. To evaluate the effect of reefs on grain-size distribution of the deposited sediment, an experiment was performed. After a year sediment samples were obtained from the shadow area, control, in the front and on the top of the reefs and then analyzed through a series of screens. The top and the shadow of the reefs had the finest grain size settled from suspension. Control and front samples showed high percentages in coarse sediments.
4. In order to evaluate the sediment and faunal transport, sediment traps were deployed at three different distances from the reefs and in different directions (S, W, E and N) during 24 hs and 4 days. Day 1, 2, and 3: not showed differences in the amount of sediment transported in relation to the distances from the reefs or in relation to orientations. Day 4: the sediment transport showed differences in relation to the distances and directions from the reefs. The meiofaunal organisms showed differences among distances from the reefs only at the day 2. The others 3 days there were not differences in relation to distances and orientations from the reefs. The total sediment and meiofaunal transport increased with the increasing of wind speed.
5. Relative water flow around reefs was estimated indirectly using the loss (dissolution) of standard plaster cylinders in a field experiment with the same design described in 4. The plaster weight loss did not This experiment showed no significant differences in relation to the distances from the reefs but showed significant differences within directions.

Our results show that *Ficopomatus enigmaticus* reefs generate a topographical heterogeneity which affect deposition and accumulation of sediment, the abundance of organisms, sediment transport and the hydrodynamic around them. This species can be considered as ecosystem engineer given that reduce the relative flow intensity generating a deposition of sediments where most of infaunal organisms live. Considering the high density of reefs, acting as a topographic heterogeneity in the lagoon, a high proportion of sediment that comes from creeks are likely deposited in the lagoon. The success of *F. enigmaticus* reefs in the lagoon could partially be increased as a result of anthropogenic disturbances, since the construction of a bridge that decreased the main flow of in the lagoon. To control or eradicate this introduced species could have a great economic impact. Moreover, this work could be extrapolated to other areas, because the observed could be repeated in the near future in any other relatively pristine areas.

Author to Contact: Schwindt
CC82, Correo Central, (7600)
Mar del Plata, Argentina,
Email: schwindt@mdp.edu.ar

INTERPRETING MARINE INVASIVE SPECIES FOR THE PUBLIC: AQUARIUM EXHIBITS AS AN UNTAPPED VENUE FOR BIOINVASIONS PREVENTION AND EDUCATION

Secord, David[1], John Rupp[2], Paul Heimowitz[3], Andrea Brannon1, Tonya Kauhi1, Rob Banes[1], Paul Wiebe1
[1]University of Washington-Tacoma, IAS Environmental Science Program
[2]Point Defiance Zoo and Aquarium
[3]Oregon State University Extension Sea Grant

Key Words: Bioinvasions Education, Bioinvasions Prevention, Aquarium, Marine Science Center, University Expertise

From green crabs to *Caulerpa taxifolia*, marine non-indigenous species (NIS) are emerging as a major international environmental threat. Recent scientific reports list invasive species as a leading cause of species endangerment and attribute billions of dollars in costs annually to the problem. Invasive species management programs continually emphasize the importance of public education, especially in light of the multiple pathways of species introductions. As a result, a variety of web pages, videos, fact sheets, workshops, and other educational tools have emerged from many organizations. However, despite obvious subject matter and audience connections, permanent or traveling exhibits at public aquariums, science museums, and marine science centers (including public wings of marine research labs) generally have not addressed marine NIS as a major theme.

Several factors may contribute to this discrepancy. Although aquatic invasions are well-known in some regions (e.g. Great Lakes, San Francisco Bay), the issue has only recently captured national attention. Aquariums may find difficulty in reconciling
the public attraction toward displays of living plants and animals with concerns over secure containment of live specimens of invasive species. Facilities may also struggle with the challenge of meshing an NIS exhibit with other permanent exhibits that may emphasize non-native aquatic species (e.g. tropical reef fish). The fact that public aquariums, marine science centers, and marine labs can and have served as pathways of NIS introductions may be reason alone that these entities should participate in NIS education efforts. Other benefits of NIS exhibits at these facilities include access to impressively large "captive" audiences interested in aquatic organisms, the opportunity to present NIS information within a broader learning environment about aquatic ecosystems, and the potential to integrate various kinds of exhibits (e.g. static displays, live organisms, hands-on interactives, videos, docent presentations).

The Pacific Northwest Marine Invasive Species Team (MIST), a partnership between the Oregon and Washington Sea Grant programs and the University of Washington-Tacoma, has launched an effort to develop aquatic invasive species exhibits at the Point Defiance Aquarium in Tacoma, Washington and the Hatfield Marine Science Visitor Center in Newport, Oregon. Both exhibits will present general information on biological invasions and examples of non-native aquatic species that occur in the Pacific Northwest and other regions. Crucial key messages include introduction pathways, NIS impacts, and prevention/control opportunities. The exhibits aim to increase public awareness, stimulate critical thinking about the role of non-native species, and influence visitor behavior relative to certain pathways (e.g. disposal of live bait), NIS detection/reporting, and even policy formation (e.g. ballast water legislation passed recently in several states).

Initial design efforts reflect several potential exhibit scales, ranging from a set of small displays that fit existing available space to a large modular exhibit that could occupy major traveling/permanent exhibit halls at other facilities. At any scale, the exhibits feature interactive components such as games about global NIS movement or hands-on demonstrations of ballast water exchange. The involvement of the University of Washington and Oregon State University allows for the participation of undergraduate and graduate students in exhibit research and development activities, and ensures that the latest university-based research is interpreted in the public forums. Through partnerships with other educational facilities and agencies, successful results from NIS exhibits at these two Pacific Northwest sites (themselves reaching several hundred thousand visitors annually) may lead to replication and expansion at many more venues on a national scale.

To illustrate this broad-based approach using the Point Defiance Aquarium example, we describe a collaborative effort including undergraduate environmental biology students, University of Washington-

Tacoma faculty, aquarium curatorial staff, local, state, and federal agencies, MIST members, and a Northwest graphic design firm experienced in scientific exhibitry. Undergraduate research and internship experiences in scientific documentation, organism husbandry, artistic design, and public interpretation of science and science policy are at the heart of this effort. We describe both the content of the proposed exhibit (concepts of invasion biology and key live organisms as examples) and the process of developing the necessary broad-based collaboration. Key messages of the exhibit include the distinction between native and non-indigenous organisms, costs and benefits of allowing new introductions (passively or actively), and lessons from specific case studies (e.g. zebra mussels, European green crabs, Chinese mitten crabs, saltmarsh cordgrass, and introduced ctenophores and sea squirts). Preliminary design plans and graphic elements of both fixed and traveling displays will be presented.

Author to contact: David Secord
University of Washington-Tacoma, IAS Environmental Science Program
1900 Commerce St., Tacoma, WA 98402-3100
Tel: (253) 692-5659
Fax: (253) 692-5718
E-mail: dave@u.washington.edu

FACTORS AND PROCESSES FACILITATING THE INVASION OF *BRACHIDONTES VARIABILIS* TO THE LEVANT BASIN

Sigal Shefer, Eli Geffen, Avigdor Abelson, and Ofer Mokady
The Institute for Nature Conservation Research, Tel-Aviv University, Tel-Aviv, Israel

Key Words: biological invasions, Mediterranean, *Brcahidontes pharaonis*, molecular markers, reproduction.

The marine biota of the eastern basin of the Mediterranean Sea is currently experiencing dramatic changes which result from massive invasions by exotic, mainly Indo-Pacific, species. The vast majority of invasions are believed to be due to human-mediated activities, notably: ballast-water conveyance and the opening of the Suez Canal. Lessepsian migration is a conspicuous example of a massive invasion of Red Sea species into the Mediterranean, which has induced changes in the biota of the Levant Basin. This large-scale biogeographic process provides a unique opportunity to study various aspects of species invasion processes. Most of the studies dealing with Lessepsian migration concentrated on describing the invading species, their distribution and their impact on indigenous biota. This wide range of studies however contributes very little to our understanding of the processes that govern and promote the invasion to the Mediterranean.

The present study is aimed at identifying the processes and conditions that facilitate the arrival and establishment of Lessepsian migrants. The research focuses on assessing species dispersal modes and routes, by using high -resolution molecular methods as well as detecting possible causes for the successful establishment of an invading species. The target species chosen as a model of successful invader is the Indo-Pacific mytilid *Brachidontes pharaonis* that invaded the Mediterranean at the beginning of the 20th century. In the last 30 years *B. pharaonis* became dominant over the rocky flats of the Israeli Mediterranean coast, displacing the indigenous mytilid *Mytilaster minimus*.

With respect to the spatial expansion of *B. pharaonis* populations the results show that at least 38 haplotypes are represented in 206 individuals sampled at 11 sites along the coasts of the Mediterranean Sea, the Gulf of Suez and the Red-Sea. A cladistic analysis using sequences of all haplotypes indicated two distinct clusters. This suggests at least two sources for the haplotypes of the three basins. Geographic subdivision of haplotypes was obtained in one of the several statistical analyses preformed. The proportion of exclusive haplotypes in each of the three basins showed that about 30% of the Mediterranean haplotypes are unique. The high proportion of exclusive haplotypes can theoretically be explained by favorable selection of rare Indo-Pacific haplotypes, but the probability for this option seems very low. A more likely possibility is the arrival of haplotypes from sources other than the Gulf of Suez and the Red Sea. In such case, the transport vector is most likely to be via ships. Another pattern that was revealed is a northwards increase in the proportion of the exclusive haplotypes in both the Gulf of Suez and the Mediterranean. This may reflect arrival of non-unique haplotypes from southern basins by natural dispersal and anthropogenic arrival of exclusive haplotypes to the ports located at the northern parts of both basins.

In an attempt to identify factors that facilitate the establishment of populations of the invading B. pharaonis and eventual takeover of Mediterranean habitats, we compared the settlement dynamics and reproductive cycle of the two species. Examination of juveniles newly recruited to artificial substrates indicates a long-term numerical advantage for the invading species, which may be important in a competition for free space with the indigenous recruits. This may be explained by various causes such as size superiority of the invader, which has biomass about 6 time higher (wet weight) than the indigenous species and higher feeding rates. Studying the reproductive cycles of the two species shows that the indigenous species has mature gonads at the end of the summer (September) gametes are then released and thereafter the gonad regresses. The invader was found to have developed gonads year round. Other studies revealed transition periods in benthic species assembly that is indicated by a decrease in live cover of substrates in May and October. The probability of available substrate patches, created during these transition periods, to be occupied by the invader's recruits is higher since the invading species presumably reproduces over a longer period of time. Finally, the invading species was found in a remarkable wide range of habitats in its native geographical range and in the invaded region, such as beach-rocks, rocky flats, Mangroves, artificial

substrates, polluted sites, and stones buried in the sand. This may contribute to the species invasiveness, since it is able to endure the conditions of various habitat types, and successfully invade remote places. In summary we suggest that two means of transport facilitate the arrival of *B. pharaonis* to the Mediterranean: 1. Natural dispersal through the Suez Canal - classic Lessepsian migration. 2. Anthropogenic arrival via ships. The study points out various characters that enabled *B. pharaonis* to establish successful populations in the recipient region, which include a long reproductive season, high competitive ability, and ecological plasticity.

Author to Contact: Sigal Shefer
The Institute for Nature Conservation Research,
Tel-Aviv University, Tel-Aviv 69978, Israel.
T 972-3-6406936
F 972-3-6407304
Email: shef@post.tau.ac.il
Avigdor@post.tau.ic.il

THE INVASION OF THE CTENOPHORE *MNEMIOPSIS LEIDYI* (A. AGASSIZ) INTO THE SOUTHERN SEAS OF EUROPE

Tamara A. Shiganova, Senior Scientist

P.P.Shirshov Institute of oceanology Russian Academy of Sciences

Key words: distribution, invasive species, fish, zooplankton, ecosystem change

In the last two decades of the twentieth century, the ctenophore *Mnemiopsis leidyi* invaded the Black, Azov, Marmara and Aegean Seas, and, recently, the Caspian Sea. Here, we compare its spatial and temporal distribution, seasonal dynamics, time and duration of reproduction, discuss factors that control its abundance throughout its invasive range and its effect on ecosystems..
An analysis of the effects of temperature, salinity, prey (zoo- and ichtyoplankton) availability and predation (by ctenophores of the genus Beroe) on *M. leidyi* population size, and effects of *M. leidyi* on zoo- and ichthyoplankton, and on fish populations in the Black and Azov Seas is also made. With the Black Sea current *M. leidyi* spreads to the upper layers of the Sea of Marmara, where it now occurs around the year. At regular intervals, the Black Sea current also takes it to the northern Aegean Sea. In contrast, it has to re-invade the Sea of Azov every spring or summer, dying out during winter when the temperature drops below 4 o C.The warm summer and mild winter temperatures, relatively low salinity and abundance of prey in the Black Sea are close to optimal for *M. leidyi*, while they are suboptimal in the northern Aegean Sea, where salinity and temperature are often too high.In the Black Sea the absence of gelatinous and other predators led to an enormous ctenophore abundance for a decade, but with the appearance of *Beroe ovata* in 1999, *M. leidyi* abundance greatly decreased.

Analysis of seasonal dynamics of *M. leidyi* in the Black Sea and in other seas of the Mediterranean basin indicates similarities in the timing of maximum abundance and biomass, in spite of some differences in the initiation and duration of reproduction. A peak biomass and density occurred in 1989 in the Black and Azov Seas and in 1990 in the other seas.The *M. leidyi* invasion negatively affected the ecosystems of the Black Sea and the Sea of Azov. The zooplankton, ichthyoplankton and zooplanktivorous fish stocks all underwent profound changes. Similar effects, but less pronounced, were recorded in the Sea of Marmara. Effects on Mediterranean food chains have, so far, remained insignificant. Salinity is probably supraoptimal here, and several predators prevent *M.leidyi* from reaching outbreak levels.
In 1999 *Mnemiopsis* appeared in the Caspian Sea and in 2000 it was first bloom of *Mnemiopsis* in the Caspian. The main area of distribution of *Mnemiopsis* is the Southern and Middle Caspian. In September it appeared in northern Caspian, but it distribution was limited by izohaline 4. Zooplankton biomass dropped by autumn 2000 due to grazing by *Mnemiopsis*, particularly great decline was recorded for Copepoda.

Author to contact: Tamara A. Shiganova, Senior Scientist
P.P.Shirshov Institute of oceanology Russian Academy of Sciences
36, Nakhimovskiy pr., 117851 Moscow, Russia
tel. 7-095-129-23-27
fax 7-095-124-59-83
e-mail: shiganov@ecosys.sio.rssi.ru

A Survival and Viability of Phytoplankton in Ballast Tanks of an Ore Carrier During a Transoceanic Voyage from Northern Europe to Eastern Canada

Nathalie Simard, Michel Gilbert and Lyse Bérard-Therriault
Fisheries and Oceans Canada, Maurice Lamontagne Institute, Mont-Joli (Quebec), Canada, G5H 3Z4

Key Words: Ponto-Caspian, Baltic, Great Lakes, species invasion

A real-time study of phytoplankton survival was conducted in September 1999 on-board the M/S Berge Nord (Bergesen DY ASA) during an 8-day transoceanic voyage from the port of Rotterdam (The Netherlands) to Sept-Îles (Gulf of St. Lawrence, Canada). Results on temporal changes in phytoplankton communities (diversity, biomass, survival and viability) in transported ballast waters during the voyage are presented. The effects of offshore ballast water exchanges on phytoplankton communities in ballast tanks were also tested by comparing changes in diversity and abundance in exchanged and unexchanged tanks (reference). Two different exchange methods were tested: the continuous 300 % flow through method, as recommended by the International Maritime Organization, and a combination of the sequential and flow through methods (ship's standard procedure). Results of laboratory experiments conducted on ballast water samples collected upon arrival and tested for the viability of non indigenous phytoplankton species will also be discussed.
Author to contact: David F. Reid,
NOAA/GLERL,
2205 Commonwealth Blvd., Ann Arbor, MI 48105-2845,
(Phone) 734-741-2019,
(FAX) 734-741-2055,
(Email) reid@glerl.noaa.gov

BALLAST WATER DISINFECTION WITH ClO_2

Dr. Greg Simpson
Independent Consultant

Key Words: ballast water, pathogens, disinfection, chlorine dioxide, bacteria

Ballast water from ships contains a variety of aquatic organisms. When ballast water is released into the environment, these organisms are introduced into local ecosystem, where they compete with indigenous organisms for food and may clog up water intake pipes. The true complexity and significance of the problem is better illustrated by the more than 200 non-indigenous species that have been identified in the San Francisco Bay area alone. Some of these organisms have no natural predators. Additionally, the delivery of large numbers of microbial species and human pathogens, spores and viruses, may pose an even greater potential health risk. Perhaps the most well known example of such an organism is the bivalve *Dreissena polymorpha*, more commonly known as the zebra mussel. Thought to have been introduced into Lake St. Claire in the mid 80's, this organism has spread at such a prodigious rate that it has been found in all the Great Lakes, through many of the natural waterways, and has been found as far south as New Orleans. It has been found on a boat being transported to the West Coast. Because of its adaptability and its fecundity (an adult female can produce as many as 1.5 million veligers in a single season), its growth has cost industry an estimated 5 billion dollars. There are many other smaller pathogenic organisms, including bacteria, spores, and viruses, that pose an even greater health risk, for example, V. cholera. Many of these organisms are planktonic; others are sessile. Sessile organisms produce biofilms, wherein a consortium of interdependent organisms can reside, protected bacteria that reside within the biofilm from the environment. Current control methods being considered include such things as a ballast water exchange program, heating the ballast water, and even chemical control including organic and inorganic biocides. This paper discusses each option from a scientific perspective, considering each type of organism, the probability of achieving control by each method. Finally, one proposed ballast treatment chemical, chlorine dioxide, is introduced. The effectiveness of this oxidant toward each type of organism mentioned is reviewed and compared against the various other control options being considered. Additionally, the following area's relating to chlorine dioxide will be address:· Safe handling and onsite generation
· Typical treatment dosages - relating to conditions found in ballast tanks
· Control methodology
· Estimated costs to treat per million gallons of ballast water
· Estimated industry costs
· Environmental impact from chlorine dioxide decomposition compounds
Ecosystem overall benefits from chlorine dioxide use

Author to Contact: Tom Perlich

EFFECTIVENESS OF BALLAST WATER EXCHANGE

G. Smith, G.Ruiz, M. Frey, L. Takata, S. Altman, K. Philips, L. McCann, C. Coss, D. Lipski, T. Huber, B. Steves, and S. Chavez

Smithsonian Environmental Research Center (USA)

Key Words: bioinvasions, ballast water, ballast exchange, efficiency, tracer

Ballast water exchange has been a primary tool for control of bioinvasions caused by global transport of organisms between source and recipient ports. But is it effective as a management strategy? From the invasions perspective this is a complex question with many aspects. Our specific question was how well does exchange remove/replace the animate and inanimate content of ballast tanks? We tested and compared the effectiveness of the empty-refill and flow-through exchange methods commonly used by the shipping industry. Empty-refill exchange is just what it sounds like. A tank is emptied to the extent possible and the original water replaced with oceanic water. Flow-through exchange occurs when water is pumped into a tank, displacing the original water while the tank remains full.

Experiments were performed aboard crude-oil tankers while these vessels were sailing in ballast between various west-coast refineries (California, Oregon, and Washington) and Valdez, AK. The experimental design included a non-exchanged control tank and one or two treatment tanks, which underwent ballast exchange. Exchange experiments were performed on eight different voyages. Six experimental voyages preformed only flow-through exchange due to ship design constraints.

We measured changes in the concentration of entrained coastal plankton and the concentration of tracers, which we introduced at the voyage initiation. For tracers, Rhodamine dye and 1 μ fluorescent microspheres were introduced via tank-top openings during the initial ballasting operation, performed in the sally port prior to sailing. To measure changes in the concentrations of biota and tracers, a variety of sample types (whole-water samples, net-tow samples, and physical measures) were collected before and after exchange events on each voyage.

Our results from inert tracer analysis show that empty-refill is more efficient than flow-through; that one empty-refill exchange can remove a very high percentage of the original water; that three successive exchanges of either type can render tracer added to the original water well nigh undetectable (>99% removal). Taken as a whole our results from biological tracer analysis parallel the inert tracer data. Despite the concordance among these data sets, it is also evident that significant variation exists among voyages and taxonomic groups.

Author to contact:
George Smith
Smithsonian Environmental Research Center
Box 28 Edgewater, MD 21037 USA
Tel: 433-482-2411
smithg@serc.si.edu

EXAMINATION OF VARIOUS FACTORS INFLUENCING ZOOPLANKTON SURVIVAL IN BALLAST TANKS AND THE DEVELOPMENT OF A BAYESIAN BASED MODEL CAPABLE OF CAPTURING THE INHERENT VARIABILITY ASSOCIATED WITH BALLAST WATER SAMPLES

Caroline A. Sutton and Keith R. Hayes

CSIRO's Centre for Research on Introduced Marine Pests

Key Words: ballast water, risk assessment, survival curves

The uptake and survival of ballast tank organisms was examined using samples obtained during 11 voyages of the BHP owned bulk carriers MV Iron Sturt and MV Iron Whyalla in Australian waters over the period 1997-99. The study focused on higher level taxonomic groupings of polychaetes, gastropods, bivalves and crab zoea because of the difficulties associated with identification of larvae of these groups to speices level. Using these groups we examined (1) entrainment in ballast by comparing taxa densities in port and tank samples; (2) the effect of ballasting method on survival and condition of larvae; and (3) mortality associated with voyage duration. Integrated water column and discrete depth sampling in the vicinity of a ballasting vessel indicates that all species detectable by these sampling methods are likely to be entrained in ballast water. Ballast tank samples indicate that predictions of taxa density in tanks based on port samples are likely to provide an underestimate of tank densities for some groups and that taxa density and diversity may vary significantly between tanks ballasted within a short time of each other. Ballasting method (gravity or pump) appears to have no significant effect on survival over voyages of short duration (< 4 days). Observations on live samples suggest however that gravity ballasted larvae of some taxa (bivalves and polychaetes) may be in better condition (more active) one and two weeks after ballasting than similar larvae that had been pump ballasted. These results suggest that pump ballasting and discharge are unlikely to provide a method of significantly reducing the viability of transported larvae. Densities of the selected taxa in ballast tanks declined over time but these changes were variable for each cruise and some tank pairs. Declines in density were typically exponential but regression coefficients for each cruise (and in some case, tanks) were significantly different and precluded the calculation of a single generic equation for each taxa. Some of this variation between tanks may be attributable to the taxonomic insensitivity associated with the use of higher taxonomic categories. Observations on live material in the laboratory, and during and at the end of voyages indicate that all samples are likely to contain some active larvae. These observations also suggest that estimates based on fixed sample alone are likely to overestimate survivorship. It is difficult to develop deterministic survival curves using this data because of the highly variable regression coefficients. Bayesian methods, however, provide a robust alternative that easily captures the variability within the data. Two approaches are presented. The first develops a posterior distribution for the life expectancy of each taxa using standard reliability techniques. The second develops a general linear mixed model (GLMM) to predict taxa density against time. The first model uses conjugate priors and is easily developed on an excel spreadsheet. The second model is developed using WinBUGS - a recently available software that uses Monte Carlo Markov Chain techniques to complete the complex integration required by the analysis.

Author to Contact: Caroline Sutton and Keith Hayes
CSIRO Marine Research
PO Box 1538, Hobart, Tasmania, Australia, 7000
61 3 6232 5386 (sutton), 61 3 6232 5260 (hayes), 61 3 6232 5485 (fax)
Email: caroline.sutton@marine.csiro.au, keith.hayes@marine.csiro.au

BALLAST WATER DEOXYGENATION CAN PREVENT SPECIES INTRODUCTIONS WHILE REDUCING SHIP CORROSION

Mario N. Tamburri[1], Kerstin Wasson[2] and Masayasu Matsuda[3]
[1]Monterey Bay Aquarium Research Institute
[2]Elkhorn Slough National Estuarine Research Reserve
[3]Sumitomo Heavy Industries, Ltd.

Key Words: ballast water, corrosion, deoxygenation, hypoxia, oxygen tolerance

One of the most important mechanisms for the introduction of aquatic nuisance species is transport in ship ballast waters. Although several ballast tank treatments to prevent transport of aquatic organisms appear promising, all existing approaches will result in significant costs to the shipping industry. Our presentation will describe a treatment that can dramatically reduce the survivorship of most organisms found in ballast waters while providing economic benefits to ship owners.

Purging of oxygen from ballast tanks with nitrogen was recently found to be a cost-effective technique for reducing corrosion. This new deoxygenation technology decreases the rate of rusting to 10% of untreated ballast tanks and represents a significant saving for ship owners when compared to other corrosion prevention approaches currently available. Recognizing the potential benefits of this technique for reducing the survivorship of many organisms found in ballast waters, we tested the tolerance of larvae from known invasive invertebrate species (*Ficopomatus enigmaticus*, *Dreissena polymorpha*, *Carcinus meanas*) to oxygen levels found in nitrogen treated ballast tanks, and detected significant levels of mortality (see Figure below). Two separate literature reviews of oxygen tolerance for various aquatic species further support the conclusion that few organisms will be able to withstand extended periods of exposure to deoxygenated ballast water.

Successful ballast water treatment technologies should meet the following important criteria: 1) effective at killing potentially damaging invaders, 2) safe for shipboard crew, 3) environmentally benign, and 4) affordable for ship owners. Deoxygenation appears to partially meet the first criterion by being highly effective at killing animal invaders (larval, juvenile and adult forms) but may be less effective for other taxa, particularly those adapted to low oxygen environments or with resistant stages such as cysts. Second, with proper equipment and training, nitrogen poses no major threats to crew safety. Third, nitrogen is relatively benign when discharged. Hypoxic ballast water would likely mix rapidly with shallow oxygenated water in harbors, and therefore create little danger for native estuarine organisms, which can withstand brief reductions in oxygen levels. Finally, ballast water admirably meets the fourth criterion. Rather than an added expense for ship owners, it actually represents a net saving, due to the significant decrease in corrosion.

Recently, the National Research Council evaluated ten candidate technologies for shipboard treatment of ballast water and concluded that intensive filtration, use of biocides, and thermal treatments held the most promise. Deoxygenation did not receive high priority, because of its failure to kill organisms resistant to hypoxia. While other ballast water treatment options may be more comprehensively effective, they come at greater environmental and financial cost. For instance, biocides may be hazardous for the crew as well as for native organisms in the vicinity of the ballast discharge. Moreover, these techniques come at a significant price for ship owners. Clearly, until mandated to do so, the shipping industry is unlikely to voluntarily install expensive ballast water treatment technologies. In contrast, we propose that widespread voluntary adoption of nitrogen treatment may result if the economic benefits for controlling corrosion become well known. Ballast water deoxygenation certainly deserves further exploration as a potential high priority treatment option, at least until international legislation mandates total mortality of ballast water organisms. While ballast water treatment has been controversial, raising conflicts between environmentalists and industry, nitrogen treatment represents a working solution that should appeal to both parties.

In summary, nitrogen treatment, by significantly reducing the level of oxygen in ballast tanks, both reduces corrosion and will cause substantial mortality of a large proportion of transported organisms. As such, it represents a rare example of a technology that simultaneously has benefits for marine conservation and industry.

Mean percent survival (± S.D.) of *Ficopomatus enigmaticus* (polychaete), *Carcinus meanas* (green crab), and *Dreissena polymorpha* (zebra mussel) larvae after 2 or 3 days of being held in water open to air (normoxia) and in water where oxygen was removed by purging with nitrogen gas (hypoxia).

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Author to Contact: Mario N. Tamburri
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road, Moss Landing, California 95039, USA,
Phone (831) 775-1743,
FAX (831) 775-1620,
Email: mario@mbari.org

TRANS-PACIFIC SHIPBOARD TRIALS ON PLANKTONIC COMMUNITIES AS INDICATORS OF OPEN OCEAN BALLAST WATER EXCHANGE

Michael D. Taylor and Lincoln A. MacKenzie

Cawthron Institute, Nelson, New Zealand

Key Words: Ballast water exchange, tracer dye, plankton, sediment-dwelling species, biological indicators.

A voyage from Japan to New Zealand via Singapore on a trans-Pacific carrier bulk was used to assess the potential for using planktonic (and sediment-dwelling) communities as indicators of open ocean ballast water exchange. The research was part of a larger project to develop methods for verifying whether international shipping has complied with mandatory controls and voluntary open ocean ballast water exchange guidelines, which was undertaken by Cawthron (New Zealand) in association with Battelle (USA), for the New Zealand Ministry of Fisheries from 1998-1999. The findings from the research discussed in this paper complement those from a parallel investigation on the use of the optical characteristics of seawater for verifying compliance. The dilution efficiency of ballast water exchanges was compared with changes in the composition and abundance of ballast tank phyto- and zooplankton taxa. Initial trials showed Rhodamine WT to be a very effective tracer dye for measuring the dilution efficiency of ballast exchange. Time series sampling during one exchange (using the flow-through dilution method (i.e. three times the volume of the ballast tank was pumped through the tank) demonstrated stratification of the dye in the initial stages of the exchange (i.e. after 0.75 the tank volume had been pumped through the tank), however all completed exchanges resulted in an unexpectedly high rate of dilution (i.e. > 99%; tank capacity = 1,435 m3) (Figure 1). Variation in dye concentration in the ballast tanks during open ocean exchanges is discussed in relation to different flow behaviours inside the tanks, including the potential for "plug flow" conditions. The high rate of dilution of the tracer dye after exchanges was also consistent with a shift in the optical signature of the ballast water from signatures typical of coastal water to those typical of open ocean water. Changes in the planktonic communities were measured by sampling the source port, ballast water, and the open ocean water during the time at which exchanges were made. Although the exchanges appeared relatively effective at reducing (i.e. by 90-100%) the overall abundance of those planktonic organisms that were previously uplifted at the source ports (i.e. Kawasaki Harbour in Japan and Singapore Harbour), such reductions must be considered in the light of variation in the survivorship of these taxa in the control tank. Relatively high rates of mortality were associated with a rapid warming (i.e. 14-26°C) of the exchanged and control ballast tanks as the vessel entered the tropics. The warming of the ballast tank water was similar to that recorded for the ambient seawater at the corresponding sampling times. Importantly, the decline in the abundance of each of several indicator taxa after open ocean exchanges contrasted with a less effective reduction (i.e. 54-58%) in the total number of source port taxa. This was a result of predominantly coastal zooplankton taxa (e.g. bivalve and barnacle larvae, and widely distributed copepods such as *Oithona* spp.) and cosmopolitan phytoplankton taxa (e.g. dinoflagellates such as *Diplopsalis* spp. and diatoms such as *Skeletonema* spp. and *Pseudonitzcschia* spp.) being uplifted during exchanges. These results are discussed with respect to: (1) recommendations that ships should exchange their ballast water in depths of at least 2,000 m; (2) major international shipping routes; and (3) the biogeography of ballast water organisms. On some shipping routes, for example, for which open ocean exchanges must be conducted in relatively shallow waters (i.e. < 2000 m) near the influence of large rivers, open ocean exchanges have the potential to replenish ballast tanks with unwanted organisms. On such routes, especially those which span a large latitudinal range (i.e. from temperate regions to the tropics), leaving the original water in the ballast tanks may be more advantageous than conducting an open ocean exchange. The use of planktonic communities as indicators of ballast water exchange requires knowledge of the spatio-temporal distributions of a wide range of ballast tank taxa, as well as an improved understanding of the key factors affecting survivorship en route (e.g. physiological tolerances, food supply, reproductive capacity and containment time). The research adds to, as well as confirms, findings from several earlier studies on the application of biological indicators of the efficacy of open ocean exchange. These include an assessment of:

· changes in the species composition and abundance of planktonic assemblages and sediment-dwelling organisms brought about as a consequence of ballast exchange;

· the incidence of coastal versus oceanic and cold versus warm water species found in ballast tanks, and taxa that are known to be relatively tolerant of ballast tank environments (e.g. dinoflagellate cysts; see Hallegraeff and Bolch 1992, Hallegraeff et al. 1997 and Mountfort et al. 1999);
· the relative abundance of viable phytoplankton communities inside ballast tanks, which may be indicative of recent open ocean exchanges (Hallegraeff and Bolch 1992 and Hay et al. 1997);
· whether or not selected target organisms that pose obvious biosecurity risks to the recipient environment are present (e.g. the northern Pacific seastar Asterias amurensis).

Figure 1. Changes in the concentration of the tracer dye Rhodamine WT before, during and after open ocean exchange of a ballast tank on the Iver Stream voyage from Japan to New Zealand during March 1999 (from Taylor and Bruce 1999).

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Author to Contact: Dr Michael Taylor
Biosecurity Research Manager
Cawthron Institute
Private Bag 2
Nelson
New Zealand
Telephone: 00 64 3 5482319
Fax: 00 64 3 546 9464
Email: michael@cawthron.org.nz

BIOLOGICAL CONTROL OF THE INVASIVE *CAULERPA TAXIFOLIA* IN THE MEDITERRANEAN SEA

Thierry THIBAUT & Alexandre Meinesz
Laboratoire Environnemnet marin Littoral
Université de Nice - Sophia Antipolis

Key Words: Biological control, *Caulerpa taxifolia*, Mediterranean, *Sacoglossa*

An invasive clone of aquarium origin, the green alga *Caulerpa taxifolia*, has been spreading rapidly throughout the Mediterranean Sea since 1984(Meinesz & Hesse 1991). From the first 1 m² of this alga discovered in Monaco in 1984, the present day situation concerns over 10,000 ha, present in 6 Mediterranean countries (Croatia, France, Italy, Monaco, Spain and Tunisia). This strain of alga is distributed world-wide by the aquarium trade as an ornamental plant, which may explain its recent apparition on the US coast of California(Jousson et al. 2000). In this country, one of the two spots *of C. taxifolia* growth was rapidly eradicated using chemical tools. As the management of invasive species is vastly different in Mediterranean countries, the official "wait and see" politics has lead to an uncontrolled situation in the Mediterranean.

As a general rule, classical methods of control involving chemical or physical processes should be used until their inefficiency as a general solution has been proven. Subsequently, the use of biocontrol agents should now be considered (Lafferty & Kuris 1996). In the Mediterranean, classical control methods are only efficient over small areas and are mainly used to protect unaffected areas of ecological interest (e.g. National Park). In order to develop a more global means of control, specific predators of *C. taxifolia* have been selected as potential biocontrol agents. Mainly because of their repellent toxins, few species feed on the Caulerpa genus. Specific grazers of this genus include certain species of the *Sacoglossa* order (Mollusca, Opisthobanchia). In the Mediterranean Sea, two sacoglossan species, *Oxynoe olivacea* and Lobiger serradifalci, commonly feed on the native *Caulerpa prolifera*, and have adapted their feeding to include the invasive *C. taxifolia*. In order to study a possible enhancement of these native predators, their main biological characteristics were assessed. Reproduction rates are high with thousands of eggs being lain every 4 days. This ensures the release of an abundance of planktotrophic veliger larvae. Field studies have show that recruitment of these organisms on *C. taxifolia* meadows is very low, however, as are sacoglossan population densities. Rearing experiments of these species have revealed the difficulties involved in feeding the pelagic larvae and allowing them to metamorphose into benthic individuals. The study of their feeding habits has shown that *O. olivacea* can successfully graze *C. taxifolia* fronds, which brings about the complete rotting of the grazed frond. A complete analysis of all the results concerning this native predator, however, has revealed that it will be difficult and costly to enhance their populations(Thibaut & Meinesz 2000). An unexpected effect was discovered during the grazing study of L. serradifalci. Instead of degrading *C. taxifolia*, the slug fragments the alga into tiny pieces which can subsequently disperse and regenerate into new plants. Native sacoglossans therefore do not seem to be appropriate biocontrol agents for C. taxifolia.

When autochtonous predators appear to be inefficient, it is possible to investigate the use of allochtonous predators. In light of this, the risks and benefits involved in the potential use of the tropical sacoglossan Elysia subornata was assessed. In its natural biota, this species only feeds on the Caulerpa genus. Experiments involving Mediterranean algae species as potential food sources revealed that E. subornata cannot switch to non-Caulerpa species. E. subornata can only survive with C. taxifolia and *C. racemosa* as its exclusive food sources. *Caulerpa racemosa* is also an introduced and invasive species in the Mediterranean. Although the risks of introducing parasites/virus/bacteria linked to E. subornata seem to be limited, additional experiments are required. Competition with the native sacoglossan species will occur only when all Caulerpa in the Mediterranean have been completely eradicated, which is ecologically impossible. The dispersal of the control agent from its initial release zone could be avoided by an efficient public awareness campaign. The feeding rate and population strategy of this tropical sacoglossan are highly efficient. Indeed, this species has a direct benthic development of the larvae with no pelagic phase. Reproduction strategy is based on regular spawns (1.5 egg-masses per week) with only a few hundred eggs produced but with a high recruitment rate. This point is crucial in establishing large populations. The strain of *E. subornata* currently being studied is temperature dependent, as individuals die at 15 °C. Its efficiency

is therefore strongly reduced (Mediterranean sea water temperatures drop to 13 °C). As no trials are possible in open sea, a computer simulation model, which takes into account both the biology and ecology of *E. subornata* and *C. taxifolia*, has allowed an efficient strategy for the use of this biocontrol species to be developed (Coquillard et al. 2000).
A preliminary cost/benefit analysis shows that *E. subornata* is a potential solution for the global control of C. taxifolia in the Mediterranean if a cold resistant strain can be found.

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Author to Contact: Thierry THIBAUT
Laboratoire Environnemnet marin Littoral
Université de Nice - Sophia Antipolis
Faculté des Sciences, Parc Varose
06108 Nice cedex 2
FRANCE
tel: -- 33 4 92 07 68 32
fax: -- 33 4 92 07 68 49
e-mail: thibautt@unice.fr

CAN BACTERIAL DATA BE USED TO VERIFY BALLAST WATER EXCHANGE?

Thomson, III, Frank K., Keun-Hyung Choi, and Fred C. Dobbs; Old Dominion University, Department of Ocean, Earth and Atmospheric Sciences

Key Words: Biolog microplates, ballast water, exchange, heterotrophic microbial communities, sole-carbon substrate utilization

Ships' ballast water represents a significant vector for anthropogenic dispersal of invasive species that threaten the structural and functional integrity of coastal ecosystems. Among the organisms present in these ballast tanks are microorganisms that potentially have dire consequences for native species, as well as for human health (Ruiz et al., 2000). Until recently, little research has been devoted to studying the diversity of these microorganisms and devising management strategies to control the microbial component of ballast water. In this presentation, we use the metabolic properties of heterotrophic bacteria to address issues of microbial diversity and verification of ballast-water exchange. Biolog microplates were first introduced as a method of characterizing and classifying microbial communities in aquatic environments by Garland and Mills (1991). Signature patterns of sole-carbon-source utilization among the 95 substrates of the original GN plates were shown to correlate with the unique heterotrophic expressions of different aquatic microbial communities. Subsequent analyses (Choi and Dobbs, 1999a; Thomson et al., 2000) demonstrated similar discriminatory abilities in the more recently introduced ECO and GN2 plates.Previous work by Choi and Dobbs (1999b) explored the efficacy of Biolog
microplates as a means of characterizing the microbial communities in ballast water from 13 ships. The present research seeks to amplify their results, in that more than 60 ships have now been sampled. Approximately half of these ships underwent open-ocean ballast-water exchange; the remainder had not exchanged their water. This analysis is ongoing and results will be presented at the meeting. The ability of Biolog microplates to delineate aquatic microbial communities has potential for applications involving ballast water characterization. Relatively rapid (48 to 72 h) assessment of ballast water samples using this technique could provide information regarding the origin of the ballast water, e.g., coastal vs. open ocean. Furthermore, such information would be useful to authorities in determining compliance to current and future ballast water exchange and treatment regulations.

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Author to contact: Thomson, III, Frank K.
Old Dominion University, Department of Ocean,
Earth and Atmospheric Sciences, 4600 Elkhorn Avenue, Norfolk, VA 23529.
(757) 683-4742. Email: fthomson@odu.edu

CLASSICAL BIOLOGICAL CONTROL OF THE NORTHERN PACIFIC SEA STAR AND THE EUROPEAN SHORE CRAB: PROSPECTS FROM SUCCESS BASED ON FIVE YEARS OF BACKGROUND WORK

Thresher, Ronald E.* and Bax, Nicholas J. (*presenter)

CSIRO Centre for Research on Introduced Marine Pests

Key Words: Biological Control, Marine Pests, European Shore Crab, Asterias, parasitic castrators

The broad distribution and large numbers of both the Northern Pacific seastar (*Asterias amurensis*) and the European shore crab (*Carcinus maenas*) in Australian waters suggest that for these species, like many other well established marine pests, the only viable long-term option for substantial impact reduction is biological control. For the last five years, CRIMP has examined the biology of these two target species and the most promising of their respective control agents, the biological castrators *Orchitophrya stellata* (Protozoa) and *Sacculina carcini* (Crustacea), while also discussing options for control with key community groups and government agencies. The results do not rule out the use of either or both parasites to control introduced populations of their hosts, but do indicate that:

· Clear definition and demonstration of suitable host specificity, and hence acceptable safety of the release, has been difficult to achieve for both these marine parasites

· The high fecundity of both hosts, in common with many marine broadcast spawners, dictates extremely high infection levels before significant reduction of impacts is likely. This may be very difficult to achieve, and

· The community and government are sceptical of the usefulness and wisdom of releasing exotic parasites to control even major pests, despite a general willingness in Australia to use biological control against a wide variety of terrestrial and aquatic pests.

We discuss the data and reasons behind these points and present the strategy that CRIMP is adopting for the long-term control of these and other pest species.

Author to contact: Thresher, Ronald E.* and Bax, Nicholas J. (*presenter)
CSIRO Centre for Research on Introduced Marine Pests
GPO Box 1538, Hobart, Tasmania 7001
Australia
phone 61-3-62325378
fax 61-3-62325485
email: Thresher@marine.csiro.au

Release from Natural Enemies and Invasion Success: Increased Performance of Green Crabs in the Absence of Parasites

Mark E. Torchin, Kevin D. Lafferty and Armand M. Kuris
Marine Science Institute and Department of Ecology, Evolution and Marine Biology

Key Words: *Carcinus maenas*; green crab; natural enemies; parasites; invasion success

Biological invasions are an increasing threat to marine systems, particularly estuaries. However, surprisingly little attention has focused on why certain invaders do so well. Introduced species often perform better than conspecifics in their native range. This is apparent in the high densities they may achieve or the larger individual sizes they attain. A prominent hypothesis explaining the success of introduced terrestrial species is that they are typically free of or are less affected by the natural enemies (competitors, predators and parasites) they encounter in their introduced range compared to their native range. To test this hypothesis in marine systems, we conducted a global comparison of the European green crab, *Carcinus maenas*, to determine if it experienced a release from natural enemies where it is introduced. We examined the native range of the green crab from Tromsø, Norway to Gibraltar, as well as every region it has invaded. To understand what regulates green crabs in Europe, we examined how body size (a measure of growth and survivorship) and abundance varied with parasitism and limb loss (an estimator of predation). To determine if introduced green crabs experienced an increase in performance and suffered less from natural enemies compared to Europe, we compared body size, abundance, limb loss and parasites of the crab where it was exotic and where it was native. In Europe, crab body size and biomass were negatively associated with the prevalence of parasitic castrators ($R2 = 0.64$, $P = 0.004$ and $R2 = 0.36$, $P = 0.039$ respectively). When we compared native crab populations with those from introduced regions, there was no difference in limb loss. Parasites, particularly highly pathogenic parasitic castrators, were substantially less prevalent in introduced populations than in European populations. Accordingly, crabs in introduced regions were larger and exhibited a greater biomass. Our results are consistent with the general prediction that introduced species suffer less from parasites compared to populations where they are native. This may substantially explain why the green crab is such a successful invader and, subsequently, why it is a pest in so many places. Release from natural enemies, particularly parasites, may also often explain the success of other introduced marine species.

Author to Contact: Mark E. Torchin
Marine Science Institute, University of California, Santa Barbara, CA 93106, USA
Tel: 805-893-3998, Fax: 805-893-8062
Email: torchin@lifesci.ucsb.edu

BEHAVIORAL ECOLOGY OF AQUACULTURE ESCAPED ATLANTIC SALMON (*SALMO SALMAR*) IN COASTAL BRITISH COLUMBIA, CANADA

J.P. Volpe, B.R. Anholt, and B.W. Glickman

Dept. of Biology (JPV and BRA) and the Centre for Environmental Health (JPV and BWG), University of Victoria

Key Words: niche, competition, salmon, residency advantage

Cultured Atlantic salmon (*Salmo salar*) is the largest legal agricultural export crop of British Columbia. Net-cage escapees are now common in many coastal rivers on Vancouver Island. We present data from field and laboratory investigations to evaluate the invasion ecology of Atlantic salmon and its effect on native salmonids, particularly niche equivalent steelhead (*Oncorhynchus mykiss*). We demonstrate that adult
aquaculture production fish are capable of spawning in a natural environment and may do
so during a period that minimizes interspecific competition. We document the presence of wild reared juvenile populations in three Vancouver Island rivers and present evidence that juvenile Atlantic salmon can successfully compete against native steelhead under present conditions on Vancouver Island. We conclude by providing an explanation for the failure of historical Atlantic salmon introductions to British Columbia and demonstrate that conditions have changed in the interim to favour present day Atlantic salmon colonization.

Author to contact: JPV
Dept. of Biology, University of Victoria, Victoria, British Columbia V8W 3N5
Tel: (250) 721 7098
Fax: (250) 721 7120
email: jvolpe@uvic.ca

BALLAST WATER TREATMENT STANDARDS: CONCEPTS AND ISSUES

Thomas D. Waite and Junko Kazumi

College of Engineering, University of Miami

Keywords: Ballast Water Treatment Standards, Ballast Water Regulations

The topic of rendering ships' ballast water innocuous with respect to the transfer of unwanted species has been debated for well over a decade. The International Maritime Organization (IMO) has had ballast water issues on its agenda for the past 13 years. However, to date, limited progress has been made with regard to the development of processes and procedures for halting the transport of unwanted species via ships' ballast.

Currently, the IMO and various port states, are suggesting that exchange of inshore ballast water with "high seas water" is at least a temporary procedure to diminish the risk of transport of unwanted species. Because of the inherent safety issues associated with ballast water exchange, however, and concerns regarding the effectiveness of the procedure on existing ships, movement has been slow to adopt "ballast exchange" worldwide. In lieu of ballast exchange, it should be possible for ships to treat ballast water to a level such that most organisms are unable to survive any voyage in the ballast. While several efforts are currently underway to evaluate treatment techniques, the fundamental issue: i.e., there are no treatment standards, or goals for treatment, has halted any positive movement of these endeavors. In fact, at this point, there is essentially no consensus concerning the level of required treatment, nor any ongoing work attempting to investigate organisms, which need to be precluded from ballast water. Because of this worldwide inability to deal with treatment criteria, ballast water treatment (other than exchange) has not made any measurable progress over the past few years.

Part of the reason that a solution for the problem of ballast water transport of unwanted species has not been achieved, is its inherent complexity. However, a solution must be found, therefore, this complexity must be bounded in a way that reasonable and productive solutions can be generated. In order to start this process, it is necessary to retreat to the beginning of the ballast issue and retrace the path, which many have walked over the past ten years. The reason for this exercise is to establish a base of consensus on several issues which constitute the core of the problem. Once a basic consensus is reached on the core issues, then the path forward, that is, development of treatment technologies and standards, will hopefully become more clear.

This paper will present concepts for the establishment of ballast water treatment standards, and document an initial structure for these standards. For example, Table 1 shows five issues that require consensus among concerned parties dealing with the ballast water treatment issue. These concepts relate directly to possible treatment alternatives for controlling the transport of unwanted species via ships' ballast. Based on a review of the existing literature, this paper will present documentation for developing a consensus on these issues.

The paper will next present a proposed concept for setting standards for ballast water treatment, focusing on selected components of aquatic fauna and flora. For example, toxic dinoflagellates are fairly well distributed in the world's oceans, and it is extremely difficult to prove that a given dinoflagellate population is non-indigenous to an area. Investigations in Australia, however, have clearly shown the presence of viable dinoflagellate cysts (*Alexandrium catenella*, *A. tamarenses*, and *Gymnodinium catetatum*) in ballast water discharge (Hallegraeff and Bolch, 1992; Rigby et al., 1993). Based on these, and other initial observations, toxic dinoflagellates have probably become the most well studied test organism in investigations of risks associated with ballast water introduction of non-native species. As such, it is proposed that toxic dinoflagellate cysts can serve as an example of a treatment marker with respect to ballast water management systems. Furthermore, size relationships and morphology of dinoflagellates and other organisms will be summarized and treatment goals utilizing these concepts will be discussed. The proposed concept on ballast water treatment standards will then focus on that portion of the plankton known as the meroplankton, which is composed of organisms associated with numerous invasion recordings. In addition, concepts will be proposed based on the existing literature, suggesting that there is a critical size limit regulating the transport of organisms worldwide. Based on the above concepts and documentation, this paper will finally propose a ballast water treatment standard which can be the basis for establishing treatment goals of all shipboard ballast water treatment systems.

Table 1. Fundamental Issues Requiring Consensus

A. The translocation of invasive species is a global problem of enormous magnitude, requiring immediate global attention.

B. At least two different levels of treatment standards will be required to effectively reducethe risk of translocation of unwanted species via ships' ballast water.

C. The translocation of microorganisms responsible for human diseases by ballast water, while occurring, is of secondary concern due to the existence of public health safeguards.

D. The intent of existing ballast treatment efficiencies (NISA & USCG) is 100 percent viaempty/refill ballast exchange, and 95 percent via flow through exchange. Ballast water systems on existing vessels are not designed for optimal exchange processes, and will therefore require calibration if used in an on-board ballast water management program.

E. The USCG currently has in-place, policies and procedures for approving ballast watertreatment equipment to be used on-board ships. The only element currently missingis the numerical standard reflecting required treatment efficiency.

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Author to contact: Dr. T.D. Waite
Associate Dean
College of Engineering
University of Miami
Coral Gables, Florida 33124
Ph: (305) 284-3467
FAX: (305) 284-2885
Email: Twaite@miami.edu

INTRODUCTION OF THE CHINESE MITTEN CRAB IN CALIFORNIA: ASSESSING THE POTENTIAL IMPACTS TO NATIVE PARASITE COMMUNITIES AND HUMAN HEALTH

Mark Walter, Carolynn S. Culver, Jenifer E. Dugan

Marine Science Institute
University of California, Santa Barbara

Key Words: mitten crab, *Eriocheir sinensis*, parasites, lung flukes, California

The San Francisco Bay estuary and associated watersheds in California have been extensively invaded by the Chinese mitten crab, *Eriocheir sinensis*. First reported in 1992, today millions of crabs inhabit thousands of square kilometers. The mitten crab, like other introduced species, has the potential to affect native parasite communities either by introducing a new parasite to the system or by serving as a new host for resident parasites. In its native range the mitten crab is an intermediate host for parasitic lung flukes (Paragonimus spp) which infect humans and other mammals through consumption and/or handling of the crab. These Asian flukes could have been introduced to the San Francisco Bay region if introduction of mitten crabs involved the release of infected animals.

North American lung flukes may also exist in areas invaded by the mitten crab. Although this region has not previously been surveyed for these parasites, their usual host, the red swamp crayfish (*Procambarus clarkii*), is scattered throughout the watersheds. This distribution of crayfish is completely overlapped and greatly exceeded by that of the mitten crab. Further, as lung flukes are not highly restricted in their use of crustacean hosts, mitten crabs may potentially amplify the prevalence of a "native" parasite by providing a new, highly abundant crustacean host. We will describe our current evaluations of the presence of Asian or North American lung flukes in crustacean hosts in the San Francisco Bay watersheds. More broadly we will discuss the implications of our findings for understanding the impact of introduced species on parasite populations and for controlling this pest species.

Author to contact: Mark Walter
Marine Science Institute
University of California
Santa Barbara, CA 93106
Tel: 805-893-8083
fax: 805-893-8062
email: walter@lifesci.ucsb.edu

TEMPORAL AND SPATIAL VARIATION IN EGG CASES OF THE *RAPANA VENOSA* FROM THE CHESAPEAKE BAY, U.S.A.

Catherine Ware*, Juliana M. Harding, and Roger Mann, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA.

Key Words: Veined rapa whelk, *Rapana venosa*, Chesapeake Bay, morphological variation, reproductive success

Invading species face a number of challenges in receptor environments if they are to become established members of the new ecosystem. Distribution data of adult life history stages reflect presence of available prey (in the case of invading predators) within the physical tolerance of the invading species; however, the functional reproductive range of the invader may be only a subset of the range occupied. It is critical to identify the functional reproductive range early in an invasion if control measures are to be effective in limiting range expansion or, preferably, eliminating the invader. The invading predatory marine gastropod *Rapana venosa* was first described from the Chesapeake Bay in 1998. Over 1200 adult specimens have been collected since that time, with the vast majority limited to a small section of the southern Chesapeake Bay. Evidence of reproduction in this receptor environment includes collection of egg masses from the field, population demographics consistent with multiple year classes, and successful culture of larval forms through metamorphosis at local temperatures and salinities from egg masses originating from field collected adults. *Rapana* lays mats of eggs with 50-300 egg cases per mat. Each case may contain 200-400 eggs. As a surrogate for determining reproductive potential in the field, adult populations from five locations in the Chesapeake Bay have been maintained and successfully bred in the laboratory during both 1999 and 2000. The five locations of origin represent a spatial cline of environmental gradients of substrate type, salinity and other physical factors. Morphological variations in the egg cases of *R. venosa* suggesting a response to this environmental cline were observed in 1999. Extensive studies of egg mass morphometrics, egg number per egg case, and viability of eggs within each case, were effected for both temporal (May through August, 1999 and 2000) and spatial (5 collection locations) clines within the known adult population in order to examine the option that successful reproduction was limited to a subset of the area from which adults have been collected. This analysis was then supplemented with spatial data describing density of breeding adults to estimate the spatial limitation of functional breeding in the lower Chesapeake Bay.

Author to Contact: Dr. Roger Mann,
School of Marine Science,
Virginia Institute of Marine Science, College of William and Mary,
Gloucester Point, VA 23062
Tel 804/684-7360,
FAX 804/684-7045,
e-mail: rmann@vims.edu

AN INVASION MONITORING PROGRAM FOR OUR NATIONS' ESTUARIES

Kerstin Wasson, Elkhorn Slough National Estuarine Research Reserve, California
Steve Rumrill, South Slough National Estuarine Research Reserve, Oregon
Drew Lohrer, North Inlet-Winyah Bay National Estuarine Research Reserve, South Carolina
Nina Garfield, Estuarine Reserves Division, National Oceanic and Atmospheric Administration

Key Words: estuary, monitoring, NERRs, prevention, rapid assessment

The National Estuarine Research Reserve (NERR) system is currently developing a broad-scale monitoring program for estuarine invasions. A workshop of invasions experts and NERR representatives is scheduled to design this program, and a summary document will be disseminated by year-end 2001. At the Second International Conference on Marine Bioinvasions, we will update participants on the general goals of NERRS invasions research, solicit feedback, and explore fruitful new partnerships.

The existing NERR System-Wide Monitoring Program (SWMP) offers an ideal platform for consistent, integrated monitoring of the extent and spread of nonindigenous species across North American estuaries. There are 25 NERR sites, representing all three coasts of the contiguous United States as well as Alaska and Puerto Rico. In addition to solid research programs funded by federal programs and state partnerships, these reserves have well-developed resource management and educational infrastructure. Thus, the NERR system is well-suited to implementing an integrated approach to invasions by exotic species.

Currently, the NERR SWMP, a nationally coordinated monitoring program implemented at all 25 reserves, focuses on abiotic (water quality and weather) parameters. Planned expansion of the SWMP scheduled for the next years will incorporate a variety of ecological parameters, with emphasis on estuarine habitat change. Assessment of the diversity, abundance, and distribution of key non-native taxa could be readily incorporated into the SWMP program. Information generated from a nationally-coordinated invasion monitoring program in estuarine habitats will allow coastal managers and resource agencies to better devise and implement effective strategies for preserving regionally distinct native biodiversity.

The potential benefits of implementing a nation-wide estuarine invasion monitoring program include:

Improved characterization of the biodiversity of estuaries. While terrestrial invaders are relatively well characterized at many of the NERR sites, marine and freshwater invaders are poorly known. For instance, a recent study at Elkhorn Slough NERR (California) revealed one new invasive invertebrate species for every two hours of search effort, and another study documented over 50 non-native marine species within the South Slough NERR (Oregon).

Early detection of new invasions. Eradication of a non-native species is usually only feasible if it is detected early on. However, there is currently insufficient monitoring to detect invasions soon after they occur. Typically non-native species are overlooked until they become widespread and problematic; by that time, it is too late for successful eradication.

Understanding impacts of biological invasions. Most reserves carry out some level of monitoring of biological communities and physical habitat characteristics. Linkages between such existing programs and non-native species monitoring can shed light on the impact of invasions on native communities and habitats. Furthermore, the NERR Graduate Research Fellowship Program, which recognizes invasions as a priority concern, is a useful mechanism for encouraging and funding research on impacts of invasions. Management efforts can then be focused on those species with the biggest negative impacts.

Identification of aspects of estuaries that make them resistant or vulnerable to invasion. Data from all NERR sites can be integrated into a unique database (with parameters such as landscape setting, habitat types, water quality, disturbance levels, and native biodiversity) that could be used to search for correlates of invasion success. Results can be applied to developing better management strategies for preventing future invasions and controlling existing aliens.

We will discuss and welcome feedback on the merits of different general approaches to invasions monitoring, including four (not mutually exclusive) tactics that have been tried on smaller scales at a few estuaries: 1) Rapid assessment teams of taxonomic experts, who can compile a preliminary species list of non-natives in one week of work at an estuary; 2) Consistent, quantitative sampling (e.g., with settlement plates or benthic cores) across multiple estuaries to assess relative abundance of both native and non-native species in particular guilds (e.g., macroscopic epifaunal or small infaunal invertebrates, respectively); 3) Teams of amateur volunteers who regularly search for new invasions by non-natives on a regional list of "least-wanted" alien species; 4) GIS mapping of the distribution and spread of key non-native species early in their invasion process, with analyses to determine habitat types most frequently invaded.

Author to Contact: Kerston Wasson,
1700 Elkhorn Road, Watsonville, CA 95076
phone: 831 728 2822;
fax: 831 728 1056;
email: research@elkhornslough.org

ReprodUCTIVE BIOLOGY OF CHESAPEAKE BAY, U.S.A. VEINED RAPA WHELKS *RAPANA VENOSA*

Erica Wescott*, Roger Mann, and Juliana M. Harding, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA

Key Words: *Rapana venosa*, Chesapeake Bay, gametogenesis, imposex, sex ratios

Successful introduction of a species requires the establishment of a viable reproductive population in the receptor environment. In the event that animals become established post-introduction, there will be temporal and spatial variation within the population in the ability to successfully reproduce resulting in foci of reproductive activity or a functional reproductive range of the invader. This study describes temproal and spatial variability in gametogenesis in veined rapa whelks, *Rapana venosa*, as a surrogate for egg laying along an environmental and spatial gradient. Laboratory populations of animals collected from Chesapeake Bay and maintained at local temperatures and salinities have been observed mating from October through July. Field collections of adult rapa whelks (shell length > 80 mm) were made year-round using opportunistic sampling based on commercial fisheries where this animal is bycatch. Representative individuals were sampled from the extreme ends of the environmental and spatial gradient of the observed population distribution. Individual animals were sacrificed and examined for gross external morphology as an indicator of sex ratio and incidence of imposex . Histological analyses were used to describe progression of gametogenesis in individual animals. The observed relationship between gametogenesis and water temperatures in animals from Chesapeake Bay is consistent with a.) previously described seasonal reproductive activity in native (Korean) populations and b.) laboratory observations of egg laying from mid-May through mid-August and field collections of egg masses in Chesapeake Bay. Collectively, these data sets indicate that the Chesapeake Bay population of rapa whelks is successfully completing gametogenesis and egg laying throughout the range of collection. These data describing reproductive capability are integrated with available demographic data from the same source to develop spatial estimates of highest reproductive output or reproductive foci within Chesapeake Bay.

Author to Contact: Dr. Roger Mann,
School of Marine Science, Virginia Institute of Marine Science,
College of William and Mary,
Gloucester Point, VA 23062
Tel 804/684-7360,
FAX 804/684-7045,
e-mail: rmann@vims.edu

PHENOTYPIC PLASTICITY OF NATIVE SOFT-SHELL CLAMS IN RESPONSE TO CHEMICAL AND PHYSICAL STIMULI FROM INVASIVE GREEN CRAB PREDATION

Lindsay Whitlow and Jim Dochtermann

Department of Biology, University of Michigan

Key Words: Phenotypic Plasticity, Predation, *Mya arenaria*, *Carcinus maenas*

To manage the impacts of marine bioinvasions, it will be useful to understand how natives respond to introduced species. Research integrating current theory on the impact of species introductions with theory on phenotypic plasticity of prey responding to predation can improve that understanding. In Maine, predation by introduced Green Crabs, *Carcinus maenas*, contributes to declines in native Soft-shell Clam, *Mya arenaria*, populations, and crab eradication efforts have proven futile (Beal, 1994). Therefore, to develop effective strategies for protecting the clams, it will be useful to understand how clams respond to crab predation.

Since native species may have evolved in the absence of predators similar to the introduced species, selection has not favored traits for avoiding this novel predator. This reasoning is often put forth as an explanation for why native populations decline following invasion. However, some species exhibit phenotypic plasticity, meaning their behavior or morphology varies with changing environmental conditions. Examining plasticity of natives in response to introduced predators may indicate the potential of native populations to survive invasion (Leonard, 1999). Also, most prey species face a trade-off between predator avoidance and feeding since hiding from predators often decreases feeding efficiency. Soft-shell clams live in mud, and burial depth affects their predator avoidance and feeding efficiency. Deeper clams should be less vulnerable to crabs because they increase crab digging time (Yamada, 1996). Clam siphons, however, must reach the mud surface to feed on phytoplankton in the water. By digging deeper to avoid crabs, clams increase the distance their siphon must reach, thus decreasing feeding efficiency. If there is phenotypic plasticity in clam behavior, clams could dig deeper to avoid crabs. If there is plasticity in clam morphology, clams deeper in the mud could increase siphon length to compensate for decreased feeding efficiency. In past studies, we found that adult clams were deeper in the mud where crabs foraged (Whitlow, in press). We also found juvenile clams in the lab responded to chemicals released into the water during crab predation by moving deeper in the mud and growing longer siphons (Whitlow, in press). Therefore, in this study we compared the phenotypic plasticity of adult clam responses to chemical and physical stimuli released during crab foraging and predation in the field.

All field experiments were conducted at the Wells National Estuarine Research Reserve in Wells, ME. We placed adult clams in 0.25 m2 mud plots covered with a tent of plastic mesh. In control ("No Crab") treatments, the tents excluded crabs from entering plots, so clams were exposed to only background chemical stimuli from crabs on the mudflats. To generate chemical and physical stimuli, we placed crabs within the tents so they disturbed the sediment over the clams as they moved. To generate only chemical stimuli, we placed crabs within smaller enclosures within the tents so they could not move over the clams to disturb the sediment. We fed clams to all crabs during the experiment to generate the chemical stimuli released during crab predation. To generate physical stimuli without crab digging or actual predation, we also placed plastic mesh on the mud surface under the tents. The mesh was small enough to prevent crab digging but large enough to allow clam feeding. To control for any effects of the surface mesh, all three crab stimuli treatments were replicated with and without mesh.

Without surface mesh, as in previous experiments, adult clams dug deeper in response to chemical and physical stimuli when compared to crab exclusion ("No Crab") treatments (Figure 1). Clams also responded equally to both chemical stimuli alone and chemical + physical stimuli. For all crab stimuli treatments, clams were significantly less deep in the mud under surface mesh. Clams exposed to chemical and physical stimuli had significantly longer siphons without surface mesh compared to under mesh. However, clam siphon length in crab exclusion and chemical stimuli treatments did not differ with and without mesh. These results suggest chemical stimuli may be sufficient to change adult clam digging behavior in response to the crabs in the field, supporting what we have found with juvenile clams in the lab. Also, deeper adult clams had longer siphons in response to chemical and physical stimuli from crabs, suggesting clams may be both behaviorally and morphologically plastic. However, the lack of siphon length differences among

clams at different depths from other experimental treatments suggests other factors may affect siphon morphology. Decreased clam depth under surface mesh may be due to physical stimuli from the mesh on clam siphons. If clams retract and close their siphons when they contact the mesh, feeding efficiency could decline. Therefore, clams may remain shallow in the mud to compensate for decreased feeding efficiency or to stretch their siphons farther up in search of space away from the mesh. Since the surface mesh was always present, feeding efficiency may have declined enough to have negatively affected clam growth. This may explain why all clams under surface mesh were less deep and why clams exposed to chemical and physical crab stimuli as well as surface mesh may have shown the least siphon growth. These results continue to emphasize the trade-off clams face between feeding efficiency and predator avoidance. In an applied aspect, these results also reinforce the need to elevate protective mesh over clam flats, since more shallow clams could eventually be more vulnerable to crabs when the mesh is removed. Overall, our research continues to work to provide information that will enable the development of more effective strategies for long-term clam protection. By integrating ecological theories on the role of plasticity in predator-prey relationships with experimental research on native responses to introduced predators, this research could strengthen the ability to predict how native species will respond to invasions into other ecosystems.

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Author to Contact: Lindsay Whitlow
Department of Biology, University of Michigan
Ann Arbor, MI 48109
p: (734) 764-1462 f: (734) 647-0884
Email: lwhitlow@umich.edu

IDENTIFYING PATHWAYS FOR MARINE BIOINVADERS INTO AND OUT OF A NEW ENGLAND STATE

Willard, Shannon M. Marine Science Center, Northeastern University
Smith, L. David. Marine Science Center, Northeastern University
Pederson, Judith. MIT Sea Grant College Program
Carlton, James T. Maritime Studies Program, Williams College-Mystic Seaport

Key Words: invasion pathways, New England, Massachusetts, trade

Introductions of nonindigenous species (NIS) can adversely affect marine ecological communities. To prevent unwanted introductions, it is critical to identify current invasion pathways and to understand their dynamics. While ballast water transport is a primary mechanism, it is not the only one, and its relative importance may vary from region to region. Our study is designed to (1) identify both shipping and non-shipping pathways for invasive marine species into and out of New England coastal states, (2) rank these as to relative risk of unintentional release, and (3) work with stakeholders to mitigate risks. To date, we have developed a comprehensive database of organizations in Massachusetts (e.g., seafood, pet, aquaculture and bait industries, research organizations) involved in the transfer of live marine organisms. We have administered a general survey to subsets of these organizations to gather comparative data on: points of origin or destination of NIS, identity of the species, frequency and volume of trade, mode of transport, likelihood of inclusion of non-target organisms in trading activities, organization's awareness of problems related to NIS, existing safeguards to prevent accidental release, and economic value of NIS transfers to the overall operation. Preliminary results indicate that Massachusetts serves as a source and sink for NIS and that the pathways vary tremendously both in the number of organizations involved and in their level of complexity. The survey area will be broadened to include other New England states in the coming year.

Author to contact: Willard, Shannon M.
Northeastern University. Marine Science Center, Nahant, MA 01908.
617-328-0161 (tel)
781-581-6076 (fax)
Email: shannpaul@aol.com

101 RECIPES FOR COD: A HISTORICAL SYNTHESIS OF MARINE AND MARITIME INTRODUCTIONS TO THE PACIFIC NORTHWEST

Marjorie J. Wonham, University of Washington
James T. Carlton, Williams College-Mystic Seaport

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

Beginning with the introduction of American shad in the late 1800s, a vigorous government-sponsored research and advertising campaign promoted the global introduction of fish, invertebrates and plants to the Pacific Northwest. In part as a result of this effective program, this region now hosts over 100 established non-native species in marine and maritime habitats. The first step in understanding ecological patterns in these invasions is uncovering their history.

We assembled a database of the known introduced marine and maritime invaders in the Pacific Northwest, from Cape Mendocino in northern California to Haida Gwaii (the Queen Charlotte Islands) in northern British Columbia. We included invertebrate, algal, plant and fish species that live in marine and brackish waters, and maritime species including salt marsh and dune plants (but only those typically submerged at high tide).

We found literature records of 133 established non-native species in this region, with several more species known to have been introduced but apparently not established, and some 80 known cryptogenic species of unclear origin. The following analysis refers only to the database of established invaders. Most of the introduced species in this habitat were invertebrates (~80%) with fewer plants (~10%), fish (~7%) and protozoans (including algae, ~3%). The species were dominated by crustaceans (~25%), molluscs (~20%) and annelids (~10%), with fewer bryozoans, cnidarians, urochordates, sponges, flatworms, and kamptozoans. Among protozoans, red and brown macroalgae were present, as well as a diatom species and several ciliates. Plants included two truly marine genera (Spartina and Zostera), plus numerous representatives of the salt marsh flora.

Introduction pathways were known for approximately 50% of the species. Of these, the vast majority (~89%) were accidental introductions and the rest were intentional. Accidental introductions included hitchhikers on vessels (45%) and on intentional introductions (40%). The relative importance of pathways varied by taxon, and over time. Starting in the late 1800s with the planting of American shad, a veritable epidemic of intentional fish introductions spread across the country. Ultimately, fish established for commercial and recreational fisheries and biocontrol included striped bass, carp, white catfish, brown trout, mosquito fish, and most recently, Atlantic salmon. During the early 1900s, a growing oyster industry began the imports of Atlantic and then Japanese oysters, bringing with them unintentional hitchhikers totaling more than 20 invertebrate, algae, and plant species. As commercial shipping increased to serve the early gold, fur, and timber trades, so the supply of ship-borne hitchhikers grew.

Overall, the invaders originated from diverse locations around the world, primarily the Western Pacific (~32%), Western Atlantic (~26%), and North and Eastern Atlantic (~20%), with far fewer from the Southern hemisphere (~7%) and Pont-Caspian regions (<2%).

Some of these invaders, such as the cordgrass Spartina alterniflora, the eelgrass Zostera japonica, the alga *Sargassum muticum* and the oyster *Crassostrea gigas*, clearly alter inter- and sub-tidal habitats. Others, including trout and carp, the cumacean *Nippoleucon hinumensis* and the flatworm *Pseudostylochus ostreophagus*, alter trophic interactions among resident species. For most invaders, however, individual ecological and economic impacts are as yet unstudied, and cumulative impacts remain almost entirely speculative.

Over the last century, as our conservation ethic has matured and public opinion has swayed, we have become increasingly aware of the consequences of biological invasions. Our challenge now is to generate a new campaign as enthusiastic as that of 100 years ago, but this time to promote the thoughtful regulation, rather than the widespread release, of non-native species.

Author to Contact: Marjorie J. Wonham,
University of Washington
Department of Zoology
Box 351800,
Seattle, WA, 98195-1800,
Tel.: 206-543-1620
Fax: 206-543-3041
Email: mwonham@u.washington.edu

ECOLOGICAL IMPACTS AND INTERACTIONS OF THE INTRODUCED RED ALGA, *KAPPAPHYCUS STRIATUM*, TO KANE'OHE BAY, O'AHU

Monica Woo

San Francisco Estuary Institute

Key Words: algae, grazing, coral reef, growth potential

The introduction of *Kappaphycus striatum* to Kane'ohe Bay, O'ahu, in the early 1970's has been followed by its spread and establishment in many parts of the Bay. The abundance and apparent overgrowth of K. striatum on live coral in certain areas of the Bay has raised the concern of management. To assess the factors that may control the distribution of K. striatum, a study was undertaken to establish minimum fragment size that could function as propagules. Caged growth potential and grazing intensities at sites of varying K. striatum abundance were also evaluated. Determination of K. striatum impact on live coral was monitored by a time series photography study. Vegetative propagation through fragmentation is an effective dispersal mechanism that has most likely contributed to the spread and establishment of K. striatum. Fragments weighing 0.05 g were capable of net growth in the field, suggesting that fragments created by physical disturbance can be carried by waves and currents to new locations where they can possibly establish. The growth potential study indicates that K. striatum is capable of net growth in all sites surveyed, suggesting that environmental differences across the Bay are not limiting its establishment. Results of the grazing intensity study suggest that herbivory does play an important role in preventing the establishment of K. striatum in areas where K. striatum is absent. No definitive explanations can be given for the abundance of K. striatum in certain areas. Through the time series photography study, overgrowth of K. striatum on live coral was observed within a one-year period. Results from these studies suggest that the spread of K. striatum is relatively slow in comparison to other algal invasions, but will continue to spread with the present herbivory levels and environmental conditions.

Author to contact: Monica Woo
1325 South 46th Street
Richmond, CA 94804 USA
phone: (510) 231-5661
fax: (510) 231-9414
email: monica@sfei.org

HISTORIC SEPARATIONS OR RECENT INTRODUCTIONS: THE PHYLOGEOGRAPHY OF *PHYLLIDICTYON ANASTOMOSANS*, WITH EMPHASIS ON AMPHI-ISTHMIAN POPULATIONS FROM CENTRAL AMERICA

Brian Wysor

The University of Louisiana at Lafayette

Key Words: Panama Canal, *Phyllodictyon*, Inter-oceanic dispersal

The Isthmus of Panama is an ideal location in which to investigate inter-oceanic bioinvasions. The Panama Canal forms part of a congested shipping route and provides a means for the transfer of biota between the Pacific and Atlantic Oceans. Completed in 1914, the canal is a freshwater lake and lock system that consists of a series of three locks at each terminus and two intervening freshwater man-made lakes. Water-flow out of the lakes is bi-directional (toward each coast) and there have been no reports of even negligible salt concentrations within the canal proper (Jones and Dawson 1973). This has lead to the notion that the freshwater of Gatún and Miraflores Lakes is a sufficient ecological barrier to the migration of marine species across the isthmus. Nevertheless, documented cases of transcanal migrations are known in various fishes (Dawson 1973, Hildebrand 1939, McCosker and Dawson 1975, Rubinoff and Rubinoff 1968, Springer and Gomon 1975) with a gobiid fish representing at least one migrant that has become established successfully (Rubinoff and Rubinoff 1968). Additionally, a xanthid crab and two species of mangrove associated marine algae previously only known from the Atlantic are recorded from the seaward most lock of the Pacific terminus (McCosker and Dawson 1975).

While unassisted migration through the canal is probably minimal the 13,000+ ships which annually navigate the Panama Canal may play a role in redistributing eurytolerant species between these and other coasts. Recent study of the marine algal flora of the Republic of Panama (unpublished data) reveals a rich amphi-isthmian flora; approximately 8% of all species known to Panama are common to both shores with nearly 20% of the less diverse Pacific flora known also from the Caribbean. Attributes of macroalgae such as the production of flagellate spores, gametes, encrusting filaments and regenerative and buoyant thalli, suggest that macroalgae may be particularly susceptible to synanthropic transport via fouled hulls or ballast water and thus to trans-isthmian migration mediated by Panama Canal traffic. The survival of some Caribbean seaweeds following freshwater exposure for times approximating a typical canal transit (~8 hrs) lends further credence to this possibility (Hay and Gaines 1984).

Evaluating inter-oceanic dispersal in macroalgae (or other organisms) is tenuous since few systematic biotic surveys have been completed along the Caribbean and Pacific coasts of Central America at appropriate pre- and post-construction time intervals. An alternative to archived records comparisons, is to implement intraspecific phylogeographic studies of species that are common to both coasts. Intraspecific phylogeography provides a high resolution framework for testing biogeographic hypotheses and is based on the premise that strong congruence exists between evolutionary history and geographic distribution of species. That is, geographic isolation of populations leads to concordant intraspecific variation in genetic information such that area cladograms correspond to phylogenetic patterns within a species (Avise et al. 1987, Soltis et al. 1997). The phylogeographic framework provides an opportunity to detect introduced species because these species may retain a geographic signature that distinguishes them from their conspecifics in the new environment. In this way, it is possible to test whether species that are separated by the Central American Isthmus have been separated historically or whether they represent recent introductions.

An intraspecific phylogeny of the diminutive, pantropical green alga *Phyllodictyon anastomosans* (Harv.) Kraft & M. J. Wynne (Cladophorales, Chlorophyta) was inferred from sequence analysis of the nuclear ribosomal DNA internal transcribed spacer regions (ITS1 and ITS2). This marker has provided resolution at the population level in the closely related green alga *Cladophoropsis membranacea* in which a Lessepsian migrant was identified in the Red Sea (Kooistra et al. 1992). In addition to three published sequences (Kooistra et al. 1992), sequence data were generated from field collected material from both shores of The Republic of Panama and from cultured isolates derived from collections of Indian, western Pacific and western Atlantic *P. anastomosans*. Preliminary data analysis suggests independent origins among two main groups of *P. anastomosans* isolates. Within one group two Caribbean Panama isolates and

a Virgin Islands isolate share a common ancestor in the Pacific Ocean from which they are clearly distinguished. The clear distinction in DNA sequence data suggests that migrations likely occurred prior to the emergence of the Isthmus of Panama and are the result of vicariant events. On the contrary, a second group of predominantly Caribbean isolates shows 100% sequence identity among all Panamanian isolates including an isolate collected from Isla Urrava, an islet guarding the Pacific entrance to the Panama Canal. The presence of an eastern Pacific *P. anastomosans* isolate which shares 100% sequence identity with Caribbean representatives is strongly suggestive of a recent introduction; its proximity to the entrance of the canal further supports this possibility.

The freshwater of the Panama Canal serves as a barrier to many, if not most, species that encounter it, however certain macroalgal species may be able to survive trans-isthmian migration. It is unlikely that additional preventive measures to inter-oceanic dispersal across the isthmus will be implemented for the Panama Canal. Nevertheless, the idea that freshwater provides an absolute barrier to species migrations of systems that depend upon salinity as a deterrent in an otherwise contiguous transit corridor must be considered with caution.

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Author to contact: Brian Wysor
The University of Louisiana at Lafayette
Department of Biology
PO Box 42451
Lafayette, LA 70504-2451
Ph: 337-482-5057 (lab)
337-482-5823 (office)
Fax: 337-482-5660
E-mail: wysor@louisiana.edu

GROWTH AND LONGEVITY OF THE EUROPEAN GREEN CRAB *CARCINUS MAENAS*, IN THE PACIFIC NORTHWEST

Sylvia Behrens Yamada, Alex Kalin and Christopher Hunt

Key Words: green crab, *Carcinus maenas*, growth, longevity, El Niño

During the summer of 1998, a strong new year class of the European green crab, *Carcinus maenas*, appeared in Oregon estuaries as well as in northern California, southern Washington and on Vancouver Island (1, 2, 3, 4, 5). This coast-wide colonization event was correlated with unusually strong El Niño currents from September 1997 to the spring of 1998. Transport of larvae by ocean currents from established populations in the south appears to be the mechanism for this coast-wide colonization event (4, 5).

Crabs from this El Niño year class grew quickly, averaging 14 mm in carapace width in June, and 47 mm in September 1998. By the end of their second summer, males averaged 70 mm and ranged from 50 to 80 mm. Molt increment studies and growth of marked recaptured crabs support this rapid increase in size. In the fall of 2000, at the end of their third growing season, some males attained a carapace width of over 90 mm. This El Niño cohort of crabs grew more rapidly than their counterparts in Maine or Belgium (Table 1). The trade-off for this faster growth rate could be a shorter life span. While the life span for *C. maenas* is 5-6 years in Maine, we estimate that it may only be around 3-4 years in Oregon (Table 1).

Table 1. Comparison of Life History Features of *Carcinus maenas* from different locations of the world.

Location # of Months below10oC Carapace Width by first winter Age at first mating MaximumLife span(years)
Maine (6) 7 3-10 mm 2-3 5-6
Belgium (7) 5 13-30 mm 1-2 3-4
Oregon < 4 32-60 mm > 1 3-4

While *C. maenas* reproduced in Oregon and Washington estuaries during the winters, the resulting recruitment during the summers of 1999 and 2000 was very sparse (1). If this pattern persists, the El Niño year class of *C. maenas* could die out without leaving enough offspring to maintain the satellite populations in the Oregon, Washington and British Columbia estuaries. Another coast-wide colonization event, however, could occur with the next El Niño.

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1) Brett Dumbauld, WA Dept. of Fish and Wildlife, Willapa Laboratory, PO Box 190, Ocean Park, WA 98640, dumbabrd@dfw.wa.gov

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Author to contact: Sylvia Behrens Yamada,
Address: Zoology Department, Oregon State University
Corvallis, OR 97331-2914, 541-737 5345
Telephone: 541-737 5345
Fax: 541 737-0501
e-mail: yamadas@bcc.orst.edu

LOCALS ONLY: ARE INTERTIDAL ANIMALS LIMITING THE SPREAD OF A CARIBBEAN BARNACLE IN HAWAII?

Zabin, Chela J.* and Michael G. Hadfield
Zoology Dept., Kewalo Marine Lab, Univ. of Hawaii

Key Words: barnacles, limpets, competition, vulnerability to invasion, invasion success

The Caribbean barnacle *Chthamalus proteus* is one of the most recent conspicuous invaders of the Hawaiian intertidal. It attains high densities in protected bays and lagoons, particularly in situations where there are few other intertidal organisms. *C. proteus* is less abundant in semi-protected waters where it co-occurs with a suite of native organisms. We examined interactions between *C. proteus* and two native animals, the barnacle *Nesochthamalus intertextus* and the pulmonate limpet *Siphonaria normalis*.
On seawalls in Waikiki the native barnacle is highly abundant and frequently overgrows or undercuts the invader. *N. intertextus* grows twice as fast as *C. proteus*, which may allow the native to compete more effectively for space. To examine whether the native barnacle is limiting the distribution of the invader, we established permanent quadrats along a seawall. In half of the quadrats native barnacles within 5 mm of invasive barnacles were removed; the remaining quadrats served as controls. Growth and survivorship of invasive barnacles in the quadrats have been tracked for 1 year. Additional quadrats were cleared of all native intertidal organisms. Recruitment of C. proteus to these quadrats and to control quadrats has been recorded for 10 months. Invasive barnacles in the treatment quadrats grew faster than those in control plots. Neither recruitment nor mortality was significantly different in treatment vs. control plots, however, suggesting that factors other than competition (such as larval supply) also play a role in the distribution of the invader.
In Kaneohe Bay, on Oahu's windward side, the invader is abundant and the native is relatively rare. An experiment similar to the one in Waikiki was established in March 2000 to test the effect of *C. proteus* on the growth, mortality and recruitment of *N. intertextus*. To date, there appears to be no effect of the invader on the native.
Interactions in Kaneohe Bay between *C. proteus* and the pulmonate limpet *S. normalis*, were also examined. The pulmonates are highly abundant (mean 30/100 cm2) at Coconut Island on a seawall that is composed of several rock types. A survey of the wall showed that the invasive barnacles were less abundant on light-colored rock and that there was an additional negative effect of pulmonate density on barnacle abundance. The pulmonates were more abundant on light-colored rock; their densities were not additionally affected by barnacle numbers. Four types of cement settlement panels (dark smooth, dark rough, light smooth, light rough) were placed in the intertidal to test for settlement preferences of *C. proteus* and *S. normalis*. Barnacles did not show a preference for color, but limpets recruited preferentially to light-colored panels. Experiments examining the effect of the pulmonates on recruitment of *C. proteus* are in progress and will be discussed.

Author to contact: Chela Zabin,
41 Ahui St., Honolulu, HI 96813
home: (808) 239-9118
work: (808) 539-7320
fax: (808) 599-4817
email: chela@hawaii.edu

ARE ESTUARIES WITHOUT INTERNATIONAL SHIPPING SAFE FROM INVASIONS BY EXOTIC SPECIES?

Zabin, Chela J.* and Kerstin Wasson

*Kewalo Marine Laboratory and Zoology Department, University of Hawaii
Elkhorn Slough National Estuarine Research Reserve

Key Words: San Francisco Bay, Elkhorn Slough, invasion vectors, spread of invasions, secondary invasions

Increased awareness of the problem of introduced marine species has led to recent surveys of several large bays with international shipping, including Chesapeake Bay, Puget Sound, Pearl Harbor, and San Francisco Bay. To our knowledge, no thorough study has been done in an embayment not connected to an international harbor. Elkhorn Slough, an estuary 70 miles south of San Francisco, in the Monterey Bay is exposed only to regional boat traffic, primarily small fishing vessels. We surveyed the slough for macroinvertebrates in 1998. Fieldwork and a literature review revealed the presence of some 50 exotic species. We found an average of 1 new invader for every 2 hours of fieldwork. A plot of number of species vs. sampling effort shows no sign of leveling off, suggesting that our total is a low estimate.
We compared origins and likely mode of transport for the invasive fauna of Elkhorn Slough and San Francisco Bay and suggest that transport vectors between vs. within regions may differ. For example, 67 percent of the invaders in the slough can be attributed to oyster culture; in the bay just 48 percent of invaders can be so attributed. While the majority of the invaders in San Francisco Bay likely arrived in ballast water or on the hulls of ships from afar, animals not associated with oyster culture probably came to the slough by way of local boat traffic or larval dispersal from established communities elsewhere. Ninety-two percent all of the invaders found at Elkhorn Slough are also found in San Francisco Bay.While much of the similarity between the two regions might be explained by their common history of oyster culture, a number of the species found in both locations are thought to have arrived in San Francisco Bay via ballast water or on boat hulls. This suggests that they arrived in Elkhorn Slough as secondary invasions. Highly invaded international harbors may therefore pose a threat to marine communities of less disturbed, nearby estuaries.

Author to contact: Chela Zabin,
41 Ahui St., Honolulu, HI 96813
home: (808) 239-9118
work: (808) 539-7320
fax: (808) 599-4817
email: chela@hawaii.edu