LOBSTERS AS MODEL ORGANISMS FOR INTERFACING BEHAVIOR, ECOLOGY, AND FISHERIES

3RD ANNUAL SEA GRANT SCIENCE SYMPOSIUM
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Sea Grant
Rhode Island

LOBSTERS AS MODEL ORGANISMS FOR INTERFACING BEHAVIOR, ECOLOGY, AND FISHERIES

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This symposium highlights the work of J. Stanley Cobb, who recently retired after 35 years at the University of Rhode Island. Stan's contributions to the field of crustacean science have been remarkable. He has served as major professor to over 25 graduate students, edited four books, and published over 89 peer-reviewed publications. This body of work has had an important influence on lobster research over the past three decades. Stan was one of the first scientists to bring underwater research methods to study marine biology and ecology. Many of his publications reflect an effort to integrate detailed behavioral observations in the laboratory with population-level observations and experiments in the field. Throughout his career, he has emphasized the need to incorporate a better understanding of biology, ecology, and behavior in lobster fisheries models and management. He and his students have worked to build bridges over a three-way divide between scientists, fishermen and managers. Undoubtedly, his work will continue to direct research and management for years to come.

The symposium includes two synthesis talks that summarize recent multi-collaborator fisheries ecology research programs on the American clawed lobster, *Homarus americanus*, and on the spiny lobster, Palinuridae. Following these talks, participants will discuss current and future challenges for the lobster fishery.

Rhode Island Sea Grant and Maine Sea Grant sponsored the symposium with funding from Darden Restaurants, Inc. Steering committee: Peter Lawton, Research Scientist, Department of Fisheries and Oceans, Canada; Rick Wahle, Senior Research Scientist, Bigelow Laboratory for Ocean Sciences, Maine; Michael Fogarty, National Marine Fisheries Service, Woods Hole, Mass.; Kathleen Castro, Director, Sustainable Fisheries Extension Program, Rhode Island Sea Grant; Barbara Somers, Research Assistant/Fisheries Extension Specialist, Rhode Island Sea Grant.

The Sea Grant Annual Science Symposium focuses on coastal science of importance to Rhode Island and beyond. The Rhode Island Sea Grant College Program is a federal-state-university partnership based at the University of Rhode Island that designs and supports research, education, extension, legal, and communications programs that foster stewardship of coastal and marine resources for the public good.

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AGENDA

8–8:30	Continental breakfast, registration, and set-up
8:30–8:45	Welcome: Barry Costa-Pierce, Rhode Island Sea Grant Director
8:45–9:25	*A short history of lobsters and J. Stanley Cobb:* Bruce Phillips, Muresk Institute, Curtin University of Technology, Western Australia
9:25–10:05	*The lobster workshops: Themes and consequences:* J. Stanley Cobb
10:05–10:35	Break and poster viewing
10:35–12:35	Synthesis talks on spiny and clawed lobsters. 45 minutes each with questions. *A coupled bio-physical model of lobster life history and circulation in the Gulf of Maine*: Lew Incze, University of Southern Maine, Portland, Maine *Recent advances in research on the behavior and ecology of spiny lobsters*: Mark Butler, Old Dominion University, Norfolk, Virginia
12:35–1:45	Lunch
1:45–4:30	Challenges discussion led by J. Stanley Cobb *Disease and population-level impacts:* Facilitated by Jan Factor, State University of New York *Metapopulations and links to fisheries management:* Facilitated by Rom Lipcius, Virginia Institute of Marine Science *Cooperative research:* Facilitated by Bonnie Spinazzola, Atlantic Offshore Lobstermen's Association
4:30–5:30	Break and cocktails
5:30–10:00	Dinner (lobsterbake and roasting) at the University Club at Mosby's, Graduate School of Oceanography

A short history of lobsters and J. Stanley Cobb

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Western Australia

J. Stanley Cobb has had a distinguished career in marine science, much of which has focused on various aspects of lobster biology and ecology. In this review I have focused on some of Stan's lobster publications, as well as his contributions to science and the community. I examine a number of both his early and recent contributions, and the overall framework of these studies in relationship to his students' publications, as evidence of the long-term impact of his research and teaching.

Finally, I will explain that in the undertaking of this review, I have discovered the real link between Stan's research and the American lobster, *Homarus americanus,* the animal that has been the focus of his life work.

The lobster workshops: Themes and consequences

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The lobster workshops started in 1977 when Bruce Phillips and I convened a small group of lobster researchers from the United States and Australia in Perth. There have been six more since then, each larger than the last. A brief history of the meetings compiled for the 20th anniversary meeting (1997 in Wellington) was published in the Lobster Newsletter. Each meeting has taken a slightly different approach to lobster science. I'll try to distill a major theme for each and, from that, follow the trajectory of lobster research (and the interests of the conveners) over the past nearly 30 (!) years. Some observations are:

- The lobster research community has become larger and better connected.
- The meetings have become more focused, despite their size, on ecology, fisheries biology, and mariculture.
- Lobster research has changed from largely descriptive to largely experimental
- Lobster research is increasingly technology-driven and collaborative

The themes probably won't point the way to future challenges, but I'll identify what now seem to be the major issues needing further research.

SYNTHESIS ABSTRACTS

A coupled bio-physical model of lobster life history and circulation in the Gulf of Maine

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Prior to 1988 there was almost nothing reported in the literature about lobster larvae or postlarvae in Maine coastal waters. In August of that year, in response to an urging and invitation proffered the previous year, Stan Cobb arrived with a boat, a net, some other sampling paraphernalia, and several students to help me determine if enough postlarvae could be found to write a proposal and establish a research program into the early life history of lobsters in this important part of their range. We found what we needed, and Stan's educated guess about the best time to try such sampling was later shown to be right in the middle of their long-term seasonal peak in abundance. Today, 17 years and countless boat trips later, a number of us have assembled a synthesis of life history data and models that present a first-order, quantitative description of egg production, larval transport, settlement, growth, and production of American lobster in the western Gulf of Maine. Industry, science, operational oceanography (the Gulf of Maine Ocean Observing System) and resource management (state and federal agencies) have all contributed, and I expect all will be involved in further development and testing of our results. I will summarize the modeling strategy and collaborations that have made this synthesis possible, and emphasize our current understanding of the spatial relationships between egg production and lobster settlement in Maine's Coastal Current System. Some of the model output is scaled to Maine's seven Lobster Management Zones, thus ensuring a link between our research and the practical world of the lobster fishery.

Recent advances in research on the behavior and ecology of spiny lobsters

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Much of Stan Cobb's career has been devoted to studies of clawed lobster behavior and ecology, and their interplay with coastal management. Yet, because of the quality and timeliness of his research and his devotion to advancing scientific communication, his influence has rippled beyond the realm of the clawed lobster. The themes that Professor Cobb has explored and his methodological approaches have been emulated by those of us working in other ecosystems with other decapods, among them spiny lobsters (Palinuridae). In recognition of the broad scope of Professor Cobb's research contributions, from larval behavior to coastal management, I proffer an equally expansive glimpse at some recent advances in research on spiny lobsters from around the world. What binds my admittedly biased selection of examples is their emphasis on behavioral ecology as the foundation for understanding and managing the system, and experimentation as the means to this end—a perspective familiar to Professor Cobb. I begin with a review of recent studies that seek to meld larval and postlarval spiny lobster behavior and physiology with physical models of flow or habitat structure to address questions about coastal management. Research results on post-settlement limitation of recruitment in clawed and spiny lobsters have long paralleled one another, and recent studies on both taxa have sought to reconcile the results of local experiments with patterns observed at larger geographic scales. I recount those efforts for spiny lobster. In striking contrast to clawed lobsters, spiny lobsters are social, and I highlight recent studies that reveal why this behavior may have evolved, how social aggregations are maintained and vary with ontogeny, and the implications of sociality for disease epidemiology. Stepping beyond population biology to examine the role of spiny lobsters in coastal marine communities, I ponder why predation by spiny lobsters is so influential in temperate ecosystems, and yet hardly discernable in its effects in

tropical settings. I end with a look at a perhaps unanticipated effect of human exploitation on spiny lobster populations, and question whether implementation of marine protected areas, as now conceived, will achieve their goals given the patterns of movement by spiny lobster.

POSTER ABSTRACTS

Preparing for habitat enhancement in Massachusetts Bay

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The installation of an artificial reef in Massachusetts Bay has been planned as part of a mitigation effort to enhance habitat for lobsters and finfish in an area adjacent to a recently established natural gas pipeline. A model was developed to select potential sites for a 2,400 m^2 cobble/boulder reef using ESRI's ArcGIS 9.0. We chose three parameters for use in our model: substrate, bathymetry, and proximity to the pipeline. These data layers were coded to represent prime, potential, and unsuitable areas for the artificial reef and were multiplied together to create a single layer map. The results of this model allowed us to identify four prime locations for potential reef sites (0.12 km^2 total); within these areas we selected 24 sites near naturally occurring bedrock. Through the use of GIS, we were able to eliminate 80 percent of potential reef area prior to field assessments. Underwater transect surveys are currently being conducted to determine the stability of the substrate at each site, as well as to classify and quantify the substrate at a smaller scale. Additional biological and physical data will be collected, including larval supply, species abundance and diversity, current speed and direction, and sedimentation rate. These data will allow us to select a site with high recruitment potential and avoid placing the reef on pre-existing productive habitat. Final reef design will include a control area with naturally

occurring cobble/boulder habitat, a second control area with open plots in the area of the artificial reef, and the artificial reef.

At the interface of lobster behavior, ecology and fisheries: Shell disease and lobsters

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The University of Rhode Island, the R.I. Department of Environmental Management, and local lobstermen have a long tradition of working together on lobster issues. When new graduate student Stan Cobb boarded the *F/V Billie II* in the 1960s with Captain Doug Smith, he inadvertently set the stage for conducting cooperative research with the industry. Forty years later, Stan's graduate students continue to work with Doug's son, Bob Smith, and other lobstermen to study lobster larval dynamics, biology, ecology, fisheries, and the emerging problem of shell disease.

Stan Cobb has been a pioneer in establishing the link between lobster biology, ecology and fisheries. Shell disease may be best described at the interface of all these fields. In 1991, a paper published by Dr. Carl Sindermann described several hypotheses underlying the concept of shell disease in crustaceans. Today, with the unprecedented appearance of shell disease in natural populations of lobster, *Homarus americanus*, it is important to expand how we view disease in natural marine ecosystems. We explore three new hypotheses in this poster: The increasing incidence of marine diseases; population-level impacts from disease; and increased evidence that anthropogenic, as well as environmental stressors, are involved. This poster will present evi-

dence to support these hypotheses obtained from several studies and data collected from the shell disease outbreak in Rhode Island.

Aspects of the biology of the spiny lobster (*Palinurus elephas*) from the Southwest coast of Portugal

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The biology of the lobster *Palinurus elephas* (Fabricius, 1787) from the Southwest coast of Portugal was studied in two different periods: in 1993–94 (March 1993 to March 1994) and in 2003 (May to July). Samples were obtained from landings and on board commercial vessels.

The data collected during 93–94 (covering a whole year) do not seem to show evidence of seasonal migrations, in contrast to other populations. The ovigerous season extended from September to March, with an individual incubation period of five months. Considering the ovigerous condition as an indicator of maturity in females, it was found the 50 percent of the females were mature at around 110 mm of carapace length. Roughly 95 percent of all females caught were below this value, accounting for 41 percent of the egg production of the population. A small percentage of large females (carapace larger than 115 mm), constituting 3.4 percent of the population, accounted for half of the egg production, showing the importance of larger individuals in the reproduction of this species.
The results were compared with the only other study on this species previously published (Vasconcellos, 1960, data from 1958). The comparison of population parameters (size structure, maturity, sex-ratio, and fecundity) shows a general decrease in average size and proportion of females, while fecundity did not differ significantly between 1958 and 1993–94.

Given the high commercial value of this species and the documented increase in fishing effort, declining landings can only be explained by a decrease in the abundance of this resource. Since the fleet is mainly artisanal, landings tend to occur in ports close to the fishing grounds; the evolution of catches in the different ports along the coast shows that, at present, catches are not only declining but also concentrating in areas around Cape Saint Vincent, suggesting a reduction in the geographical distribution of the species. All information analyzed points at a situation of clear overexploitation of this resource.

Aging the American lobster (*Homarus americanus*) – Does size matter?

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Traditionally, the age of American lobster (*Homarus americanus*) has been determined using body size (mm carapace length). Recent studies demonstrated that lipofuscin (aging pigment) accumulations in the brain have been more accurate predictors of age in decapod crustaceans. The correct aging of American lobster is important because age at harvestable size is one parameter used in models that assess lobster stocks. Currently, it is believed that only two year-classes (ages 5 and 6 years) support the lobster trap fishery. If length-based models used for American lobster assessments were converted to age-based models using age-length keys generated with olfactory lobe cell mass analyses, annual lobster landings could be distributed across 5 to

8 year-classes (ages 3 to 9 years). Given recent events in Western Long Island Sound, accurate age determination in the current population could also give an indication of age-class(es) most heavily impacted by the die-off in 1999.

The purpose of this research project is to apply the lipofuscin method of age determination to the Long Island Sound population of American lobster. To generate an age-based standard index of lipofuscin concentration in the olfactory lobe cell mass of the brain, a series of known-age animals ranging from 1 month to 5 years old have been analyzed by confocal laser microscopy of fixed brain tissues. Prior to dissection, lobsters were sexed and carapace length measured to the nearest millimeter. Following decapitation, an incision is made along the lateral line of the dorsal surface of the carapace. This portion of the exoskeleton is removed, exposing the cardiac sac and underlying connective tissue. The brain tissues were removed and fixed immediately according to standard procedures using 10 percent neutral buffered formalin. Approximately five sections (5 to 8 micrometers) were collected from each tissue and examined using a BioRad CellMap Confocal Microscope equipped with LaserSharp 2000 imaging software to analyze lipofuscin autofluorescence. The average number and size of individual lipofuscin granules versus the total area of the cell mass were calculated using NIH Image J software. Using these quantifications, the area fraction of the cell mass occupied by the granules was determined and used as an index of age. Although preliminary, the data for known-age animals are consistent with previous studies. These data showed that average particle size and percent mean area occupied by lipofuscin granules increased with age. Animals processed ranged in age from 2.5 to 4 years old and average particle size increased 100-fold while the area fraction increased from approximately 1 percent to 20 percent. These indices from laboratory-raised, known-age animals will be compared with those levels from the wild Long Island Sound population in an effort to determine age.

Keywords: *Homarus americanus* – Age pigment – Lipofuscin – Fluorescence

Epizootic shell disease in American lobster (*Homarus americanus*) in Massachusetts coastal waters: Interactions of temperature, maturity, and molt cycle

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An outbreak of shell disease in American lobster (*Homarus americanus*) over the past several years has generated a great deal of attention and concern regarding its causes and its spread into New England coastal waters. An examination of the disease within Massachusetts state waters was conducted from 2000 through 2004. The average incidence observed in our data was relatively low (males 3 percent and females 8 percent). Female lobsters were more likely to exhibit disease symptoms than males, and larger lobsters were more likely to possess disease symptoms than smaller lobsters. Disease incidence was highest in May and June, immediately prior to the molting period, and decreased dramatically through the molting season. We detected a north to south latitudinal gradient of increasing shell disease prevalence along the Massachusetts coast. Over the course of our study period, we found relatively constant low levels of shell disease in both the Gulf of Maine and Outer Cape Cod regions. However, a significantly higher level of shell disease was recorded in the Buzzards Bay region, indicating important differences in regional prevalence of disease. Our data suggest that this gradient in shell disease may be related to an interaction between water temperature, sexual maturity, and molt cycle. There is a significant correlation between disease incidence in Buzzards Bay and a series of warmer-than-average water temperatures from 1999 to 2003, which suggests that temperature may be a primary factor related to the recent outbreak of epizootic shell disease.

Daily patterns of locomotion expressed by American lobsters (*Homarus americanus*) in their natural habitat

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Stan Cobb's laboratory studies in the 1970s demonstrated that lobsters are primarily nocturnal. Although this pattern has been substantiated by subsequent SCUBA observations, few quantitative studies of lobsters' activity in their natural habitat have been carried out due to the difficulty of obtaining continuous data in the marine environment. In order to test the nocturnal activity hypothesis, we used ultrasonic telemetry to quantify the small-scale movements and activity patterns of American lobster, *Homarus americanus*, inside a 50m-by-50m mesocosm. Forty-five lobsters of both sexes, ranging in size from 62mm to 93mm in carapace length, were continuously tracked for 2 to 10 days in 2002 and 2003. The mean distance traveled by all lobsters was 851.7 ± 616.2 meters/day (35.4 ± 25.6m/hr). A mixed effects model revealed no significant differences in the distances traveled by males and females ($p=0.563$) or lobsters of different sizes ($p=0.729$). Lobsters moved furthest during the night (43.2 m/hr), followed by dawn (42.1 m/hr), dusk (31.2 m/hr) and daylight hours (27.8 m/hr). There were statistically significant differences in the rates of locomotion exhibited during the night vs. the day ($p=0.0005$) and at dawn vs. the day ($p<0.0001$). There were no significant differences in the rates of movement expressed during dusk and the day ($p=0.528$). Although, as a population, lobsters expressed greater rates of movement at night and dawn than they did during the day, there was a high degree of variability in terms of the time of day when individual lobsters were most active. Moreover, individuals rarely expressed the same activity pattern from one day to the next. For example, they would be nocturnal during the first day, diurnal the next and then remain continuously active for the next 24 hours. These findings expand upon Stan Cobb's earlier work and provide evidence that the movements of lobsters in the field are

strongly influenced by factors other than their endogenous tendency to be nocturnal, and as a result, the patterns of activity they express in their natural habitat are quite variable.

The Florida Keys chronicles: Successfully interfacing spiny lobster behavior, ecology, and fisheries

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The fortuitous discovery by James M. Marx of the algal settlement habitat of postlarval *Panulirus argus* in south Florida set in motion two decades of research that eventually elucidated the key regulating parameters of regional spiny lobster population recruitment. However, our initial studies were aimed at understanding the basic behavioral ecology and ontogeny of the previously termed "missing stage" in the life cycle. It took us several years to learn enough about post-settlement benthic life and how it connected with the better-known juvenile phase to recognize the potential to perform ecological-scale field manipulations to test recruitment hypotheses. The strong interest, cooperation, and support from the FWC (Florida Fish and Wildlife Conservation Commission) made it possible to conduct a rigorous schedule of year-round, multi-year, Keys-wide programs to assess the comparative effects of postlarval supply and post-settlement mortality—the latter linked to sheltering habitat from intense predation. The poster chronicles the key studies and findings from 1984–2004.

What does catch composition in individual lobster traps tell us about lobster behavior?

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Recent studies of American lobster, *Homarus americanus,* indicate that behavioral interactions in and around traps influence subsequent catch per unit effort (CPUE). In order to test this theory over a large portion of the range of this species, we analyzed the composition of the catch from individual traps using datasets from commercial and research fishery traps including those in Rhode Island (n=1956), New Hampshire (n=383) and Maine (n=5605). These analyses focused on three questions:

1) What is the most common number of lobsters captured in a trap?
2) How does the ratio of male to female legal lobsters change as the total number of lobsters in a trap (i.e., CPUE) increases?
3) How does the ratio of legal lobsters to sublegal lobsters change as the number of lobsters in a trap increases?

Within the scope of the datasets considered, a large percentage of traps captured zero, one, or two total lobsters with a large number of all traps catching at least one legal lobster. Of the traps with a CPUE =1 legal lobster, the composition of the catch was skewed toward females. As CPUE in a trap increased from 1 to 10 lobsters, the relative proportion of sublegal lobsters also increased. These trends

were surprisingly consistent in all datasets despite the large geographical range between study areas and the seasonality of trap deployments. This suggests that certain common behavioral rules may influence the size, sex, and number of lobsters captured in traditional traps.

The complete larval development of the Indo-Pacific spiny lobster *Panulirus penicillatus* (decapoda, palinuridae) in culture

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The ability to culture larval lobsters is of paramount importance to the commercial development of effective aquaculture methods. This knowledge could also help to quantify relevant behavioral traits that influence lobster distribution and subsequent recruitment. Cobb's extensive studies on the early life history of lobsters corroborate this paradigm and elegantly document these links. Recently, we developed two separate laboratory-culturing strategies that yielded complete larval development from egg to puerulus in the spiny lobster, *Panulirus penicillatus*. Individual phyllosomal culture of 10 newly hatched animals was carried out in a static seawater system. Two of the 10 phyllosomas held at 24.5°C–26.0°C metamorphosed after 20 molts to the puerulus stage at 256 and 294 days respectively (final body lengths=30.80 mm and 32.0 mm). Mass culture of 500 newly hatched phyllosomas was also carried out in two specialized acrylic flow-through seawater tanks. Of the 500 larvae animals, 215 were randomly sampled and were morphologically staged (10 distinct

stages were observed and documented as well as two sub-stages). Seven of the phyllosomas that were mass cultured metamorphosed to the puerulus stage under a constant temperature regime of 24°C (mean days=302.4 days and mean final body length=32.13mm). This species is now one of only six palinurid lobsters to be cultured completely from hatch to settlement stage. This new understanding of larval development will facilitate modeling of larval distributions and durations in the field.

Home range dynamics of the American lobster, *Homarus americanus*

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Stan Cobb was one of the pioneers in the field of lobster biology, and much of his early work focused on lobster territories and shelter–related behavior. In the past three years we have been using new technologies to expand our knowledge about lobster territories and home ranges. In 2002–2003 we tracked 24 lobsters, ranging in size from 63 to 92 mm CL, for 3 to 7 days using a VEMCO VRAP fixed array ultrasonic telemetry system. In order to prevent lobsters from wandering outside the detection range of the buoy array, the lobsters were tracked inside a 3125m^2 enclosure (mesocosm) that we constructed in 10 meters of water in a cove along the New Hampshire seacoast. The habitat within the mesocosm was 80 percent sediment and sand, with an eelgrass bed occupying the remaining 20 percent. Daily home ranges were calculated using a fixed kernel function within the Animal Movement Analysis Extension written for ArcView 3.3 (Hooge et al., 2001). The kernel function calculates a series of utilization distributions (UD) that estimate the probability of finding an animal in a given area. We used the 99 percent UD to define the home ranges and the 50 percent UD to define the core areas of activity. Based on a total of 123 complete days of data (with

an average of 282 fixes each day), the average home range was 1390 ± 289 m^2 (SEM; range: 20-4905m^2). Many lobsters changed core areas on a daily basis, while others maintained one core area for several days. Nine of the lobsters (38 percent) maintained the same core area for the entire time they were tracked. On average, lobsters had two distinct core areas over the course of five days. The average size of the core areas was 98.2 ± 19.6 m^2. There was a significant difference ($p=0.022$) between the size of the home ranges for males (993m^2) vs. females (2010m^2). However, we found no correlation between the sizes of lobsters and their home ranges. During 2004, we tracked eight additional lobsters outside the mesocosm and the results obtained were consistent with the results obtained from lobsters inside the mesocosm.

Shelter competition between *Homarus americanus* Milne Edwards and *Homarus gammarus* L.: Assessing the morphological correlates of behavioral dominance

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The occurrence of the American lobster (*Homarus americanus*) in Norway has raised questions about its prospects for further invasion of Scandinavian waters and competitive interactions with the native European lobster (*Homarus gammarus*). Shelter–related behavior and

competition between American and European lobsters were evaluated by way of inter-specific comparisons of shelter preferences and utilization of lobsters released in a mesocosm tank with surplus of identical shelters. The outcome of interspecific competition was tested in a shelter–limited context where equal numbers of the two species of similar body size and sex were present in the tank. In single-species treatments, we observed no behavioral differences between the two species with respect to choice, utilization, or retention of the shelters, and prior residence was not of importance to the outcome of shelter competition. In treatments where the two species were together, we observed significant differences in their competitive abilities. More than 80 percent of the resident American lobsters retained shelter when approached by introduced European lobsters, and more than 70 percent of the introduced American lobsters evicted resident European lobsters from their shelters. Although European lobsters had 5 percent longer carapaces than American lobsters of equivalent body mass, American lobsters had nearly 25 percent greater claw volume. Our results suggest that claw size is an important determinant of competitive ability in lobsters, giving American lobsters an advantage in shelter competition with European lobsters of equal body size.

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(Also to be presented as a poster at the ICC6 Invasive Species, in Glasgow, UK 18-21 July 2005)

Possible demographic consequences of intraspecific shelter competition among American lobsters (*Homarus americanus*)

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Cobb's (1971) pioneering experiments demonstrated how habitat architecture and body-size scaling influence intraspecific shelter-related behavior among American lobsters. His subsequent work and that of coworkers indicated shelter availability and competition might determine the local carrying capacity and demography of this species. With that background, I sought to determine how shelter spacing influences population density, the intensity of intraspecific competition, and body size distribution of American lobsters. For this, I cut identical hemicylindrical PVC shelters and placed them in sets of 10 in mid-coastal Maine at 10 m depth, variably spaced at 0.25, 0.5, 1.0, 1.5, and 2.0 m between adjacent and opposing shelters. Control shelters were spaced two meters apart but without opposing shelters. Back doors on each shelter caused occupying lobsters to face opposing shelters when present. The spatial arrays of shelters were run simultaneously and recorded daily in situ during June through August for a period of four years. The location, size, sex, and number of claws of all lobsters were recorded. Claw tags were placed on lobsters to determine if they return regularly to the arrays; they did not. Within the footprint of the experiment, lobster population densities scaled with shelter densities when shelters were closer than 1.5 m apart. At that and at higher shelter densities, the proportion of occupied shelters declined. In situ video recordings documented direct intraspecific competition resulting in shelter evictions and lower proportions of all shelters occupied when population densities exceeded about 0.6 per m^2. Under this high competitive pressure, the average size of the lobsters remaining in the shelters was consistently smaller than the control or low shelter density treatments. Lobsters may be compelled to compete with all lobsters within their range and agonistic behavior of detection and this range increases with body

size. In shallow, high-population-density environments (average densities in Maine can exceed two per m^2), the only adaptive solution for large lobsters may be to diffuse from areas of high lobster population density to areas of low population density. This demographic diffusion could contribute to the well-known segregation of large lobsters from smaller lobsters that live at highest densities near their nursery grounds in shallow inshore coastal zones.

Laboratory experiments on artificial reefs for American lobsters

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Canadian fisheries policy requires that fish habitat destroyed by marine construction be replaced or productive capacity of other habitat be increased. In the near-shore waters of Nova Scotia, lobster habitat can be chosen as the standard for replacement. It is typical of much inshore, it supports a diverse marine community, and the lobster fishery is the most valuable fishery in Atlantic Canada. This laboratory study investigates design features for artificial reefs as enhanced lobster habitat. Experiments using brick shelters tested the ability of two lobster sizes (50-59 and 82-89 mm CL) to enlarge shelters by digging in sand/gravel. If the gravel size was 0.5 inch, the occupancy rate of shelters that had to be enlarged to be occupied was equal to that of shelters that required no enlargement. If gravel size was 1 in. or 2 in., fewer shelters requiring enlargement were occupied, the excavation took longer, and the larger lobsters excavated more shelters than the small. In an experiment in which equal-sized piles of three sizes of rocks were placed on sand/gravel and hard

bottom, more 50-59 mm and 70-79 mm CL lobsters occupied rock piles on sand/gravel. Lobsters 50-59 mm CL occupied piles of large-flat, large-round, and small-round rocks in decreasing abundance. Nearly all lobsters were located between the rocks and the substratum rather than among the rocks. A third experiment compared occupancy of 0.7 m and 1.2 m diameter rock piles by 60-69 mm CL lobsters where both pile sizes were of large rocks on sand/gravel. The larger piles attracted more lobsters, but neither the number/m^2 nor number/m circumference were significantly different. In summary, the substratum beneath a rock reef should be considered as part of the reef's structure. Reefs housed more lobsters if the reef was placed on substrate they could excavate. If the substrate was a sand/gravel mix, excavation will be easier if the gravel was smaller than 1 in. Because lobsters mostly occupy shelters under the reef, reefs several rocks thick would be a waste of resources. Flat rocks probably accommodate a larger range of lobster sizes than round rocks.

Integrating habitat into population assessments: A random stratified approach to estimating relative abundance of American lobster, *Homarus americanus*

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Fishery-dependent trap sampling has long been used to characterize commercially important crustacean populations. However, CPUE estimates can be biased and are potentially non-reflective of relative abundance because fishermen maintain optimal catch rates by moving fishing gear to coincide with seasonal movements of lobster. For this reason, lobster population assessments are currently based on relative abundance indices generated from trawl surveys. Trawl survey data also have potential biases, mainly associated with the inability of the gear to

fish in all productive lobster habitats, such as rock and ledge bottom. We have developed a random stratified ventless trap survey in order to effectively sample lobster relative abundance and to address the variables of depth, substrate, and trap efficiency. We used ArcGIS 9.0 as a tool to stratify the survey by sediment type and bathymetry. The study area, Massachusetts Bay, was partitioned into 15-second latitude/longitude cells, each characterized by substrate and depth. The combinations of substrate and depth in the bay yielded a total of 11 strata types from which an equal number of sampling stations were randomly drawn. Each station will be sampled bimonthly using a six-pot trawl, alternating vented and ventless lobster traps. Standardizations will account for trap design, bait, and soak time. Results are expected to document the relative importance of substrate type and depth pertaining to lobster abundance, size distribution, and seasonal movements. Preliminary results will be presented.

Spatial patterns of predation on the American lobster

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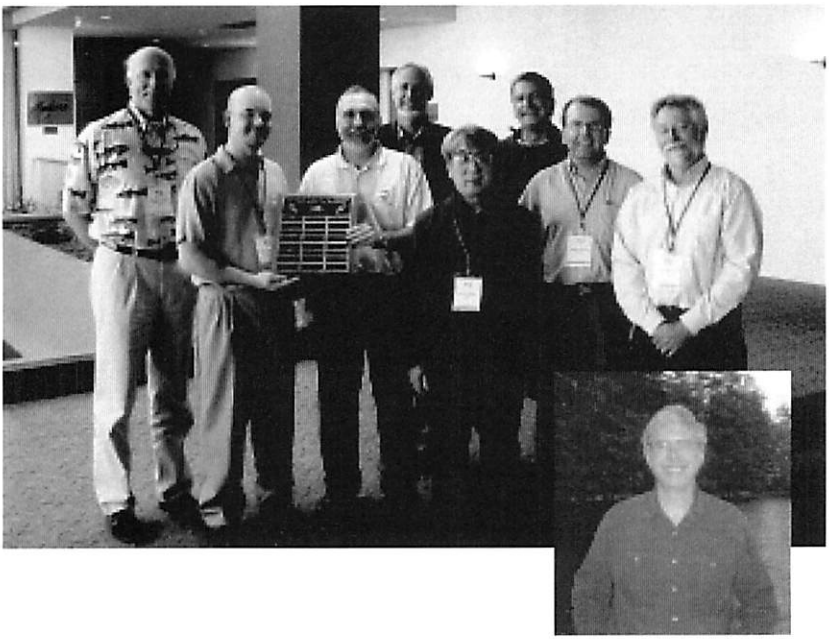
This study evaluates regional differences in predation on the American lobster *Homarus americanus* from Maine to Rhode Island. Predation is potentially an important source of post-settlement natural mortality for juvenile lobsters. Our underlying hypothesis is that predator-mediated bottlenecks in the life history of lobsters are more severe in southern New England, where preliminary data suggest that predatory fishes are both more abundant and diverse. We are assessing how strongly predation pressure as measured in the field with video-monitored tethering experiments correlates with the abundance and species composition of predators from surveys of fishes and decapods along the coast. Counter to expectations, tethering experiments to date indicate that predation rates are constant across all regions. We suspect this result may be an artifact of tethering (*sensu* Peterson & Black,

1994. Mar. Ecol. Prog. Ser. 111: 289-297), in that the composition of predators changes from southern New England, where tethered lobsters were primarily attacked by fishes, to northern New England where they were attacked by crabs (*Cancer* spp.). We hypothesize that crabs are less effective predators than fishes on untethered lobsters, and plan experiments to explicitly test that question.

The Lobster Workshops

The first lobster workshop was held in Perth, Australia, in 1977, followed by those held in San Andrews, Canada (1985); Havana, Cuba (1990); Sanriku, Japan (1993); Queenstown, New Zealand (1997); Key West, Florida, U.S.A. (2000); and Hobart, Tasmania (2004). The next workshop is scheduled to be held in 2007 in Prince Edward Island, Canada.



Previous and future conveners of the International Lobster Workshops join together for a photo at the Tasmanian workshop. The plaque represents the history of the Lobster Workshops. From left: Mark Butler (Key West), Jean Lavallee (PEI), Stewart Frusher (Tasmania), Bill Herrnkind (Key West), Jiro Kittaka (Japan), Nick Caputi (Australia), Peter Lawton (St. Andrews), and John Booth (New Zealand), and Stan Cobb (inset). Missing past conveners are Bruce Phillips (Australia), Alan Campbell and Bob Elner (St. Andrews), and Julio Baisre and Raul Cruz (Cuba).

"I once heard a clergyman at a lecture describe a lobster as a standing romance of the sea; an animal whose clothing is a shell, which it casts away once a year, in order that it may put on a larger suit; an animal whose flesh is in its tail and legs, and whose hair is on the inside of its breast; whose stomach is in its head, and which is changed every year for a new one, and which new one begins its life by devouring the old. An animal which carries its eggs within its body until they have become fruitful, and then carries them outwardly under its tail; an animal which can throw off its legs when they become troublesome, and can in a brief time replace them. Lastly, an animal with very sharp eyes placed in moveable horns."

—Prof. J.W. van der Voort, 1883, The Water World