

# THE AMERICAN LOBSTER IN A CHANGING ECOSYSTEM



★ A US-Canada Science Symposium 

27-30 November 2012  
Portland, Maine  
agenda & abstracts

<http://www.seagrant.umaine.edu/lobster-symposium>

## **About the symposium**

The status of the American lobster over the last decade is a story of contrasts. While lobster numbers from the Gulf of Maine northward have climbed to historic highs, southern New England has been plagued by disease and mass mortality. Coastal communities in Atlantic Canada and Maine are more dependent on the lobster fishery than ever before. For the first time, southern New England harvesters face a moratorium on lobster fishing.

Fundamental changes have occurred over the past few decades in the climate and food web of the Northwest Atlantic, as well as the economics of fishing. After decades of relative stability in the fishery, *Homarus americanus* faces a changing environment and must be viewed in this context. Fishery managers grapple with how to integrate traditional single-species management with the mandate for ecosystem-based approaches, and major research initiatives are generating interesting results across the species' range. The co-chairs conceived the symposium as a forum for new findings, aiming to identify region-wide research gaps and priorities, and catalyze new research collaborations.

## **Symposium steering committee**

Paul Anderson, Maine Sea Grant College Program (co-chair)

Andrea Battison, CrustiPath, Prince Edward Island (co-chair)

Richard Wahle, University of Maine (co-chair)

Robert Bayer, Lobster Institute, University of Maine

Cathy Billings, Lobster Institute, University of Maine

Kathy Castro, University of Rhode Island

Dounia Daoud, Homarus Inc., Maritimes Fishermen's Union, New Brunswick

John Garland, Clearwater Seafoods, Nova Scotia

Jonathan Grabowski, Northeastern University

Patty King, Fishermen and Scientists Research Society

Patrice McCarron, Maine Lobstermen's Association

Angelica Silva, Fisheries and Oceans Canada, Bedford Institute of Oceanography

John Tremblay, Fisheries and Oceans Canada, Bedford Institute of Oceanography

Carl Wilson, Maine Department of Marine Resources

## **Sponsors**

Aquatic Science & Health Services | Consulate General of Canada | Fisheries and Oceans Canada | Lobster Institute | Maine Coastal Program | Maine Department of Marine Resources | Maine Sea Grant | National Oceanic and Atmospheric Administration | National Sea Grant Office| Newfoundland Labrador Fisheries and Aquaculture | Nova Scotia Fisheries and Aquaculture | Northeast Sea Grant | Ocean Choice International | Prince Edward Island Fisheries, Aquaculture and Rural Development | University of Maine | University of New Brunswick | University of Rhode Island

Special thanks to Susan MacPherson, Great Gatherings, LLC, for program coordination, and to Maine Sea Grant staff for assistance and support.

## **Agenda at-a-glance**

### **Tuesday 27 November**

4:00 pm–8:00 pm	Lobby	Registration Open
6:00 pm–8:00 pm	New Hampshire	Welcome Reception

### **Wednesday 28 November**

7:00 am–5:00 pm	Lobby	Registration Open
7:30–8:30 am	New Hampshire	Continental Breakfast
8:30 am	Vermont	Welcome remarks
9:00 am	Vermont	Plenary Session I
9:30 am	Vermont	Plenary Session II
10:00 am	New Hampshire	Break
10:30 am–12:00 pm	Rhode Island Massachusetts	Concurrent Session I Concurrent Session I
12:00–1:30 pm	New Hampshire	Lunch
1:30–3:00 pm	Rhode Island Massachusetts	Concurrent Session II Concurrent Session II
3:00 pm	New Hampshire	Break
3:30–5:00 pm	Vermont	Moderated Discussion

Dinner on your own

### **Thursday 29 November**

7:00 am–5:00 pm	Lobby	Registration Open
7:30–8:30 am	New Hampshire	Continental Breakfast
8:30 am	Vermont	Announcements
9:00 am	Vermont	Plenary Session III
9:30 am	Vermont	Plenary Session IV
10:00 am	New Hampshire	Break
10:30 am–12:00 pm	Rhode Island Massachusetts	Concurrent Session III Concurrent Session III
12:00–1:30 pm	New Hampshire	Lunch
1:30–3:00 pm	Rhode Island Massachusetts	Concurrent Session IV Concurrent Session IV
3:00 pm	New Hampshire	Break
3:30–5:00 pm	Vermont	Moderated Discussion
5:30–7:30 pm	New Hampshire	Poster & Awards Reception

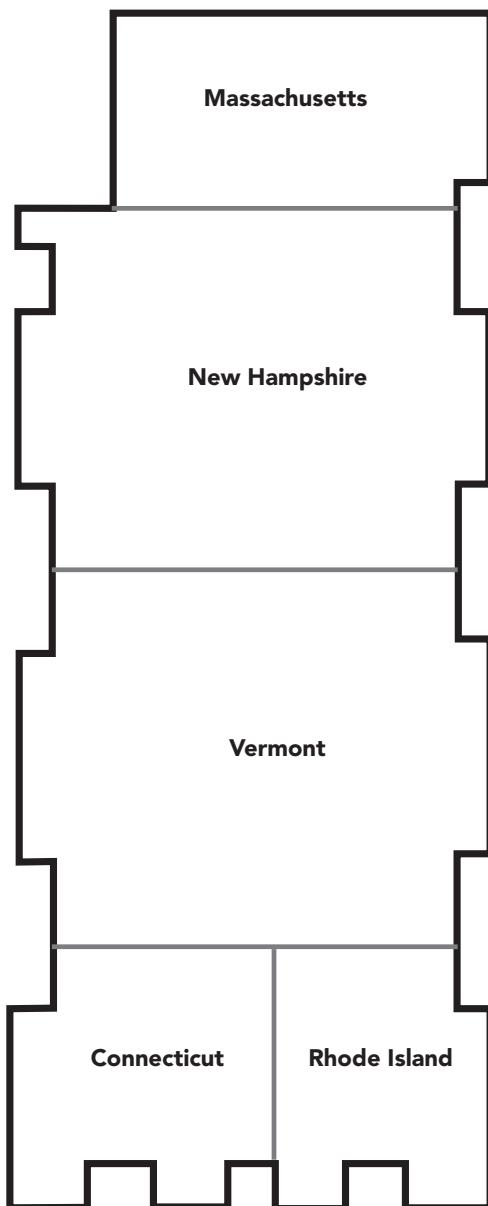
### **Friday 30 November**

7:30–8:30 am	Vermont	Continental Breakfast
8:30–10:00 am	Vermont	General Roundtable Discussion/ Meeting Recap and Next Steps

**Tuesday 27 November**

<b>4:00–8:00 pm</b>	<b>Registration Open</b>	<i>Lobby</i>
<b>6:00–8:00 pm</b>	<b>Welcome Reception</b>	<i>New Hampshire</i>

**State of Maine Grand Ballroom**



**Lobby**

**Wednesday 28 November**

7:00 am–5:00 pm	Registration Open	Lobby
7:30	Continental Breakfast	New Hampshire
	<b>Welcome Remarks</b> Richard A. Wahle, Andrea Battison, and Paul Anderson	
8:30	Patrick Keliher, Commissioner, Maine Department of Marine Resources  Aaron Annable, Consulate General of Canada	Vermont
	<b>Plenary Session I: Anthropogenic and Environmental Stressors</b> <i>Complex etiologies and the emergence of diseases in lobsters from Long Island Sound.</i>	
9:00	Jeffrey D. Shields, Virginia Institute of Marine Science, College of William & Mary	Vermont
	<b>Plenary Session II: Food Web Dynamics</b> <i>Lobster dynamics in a brave new ocean.</i>	
9:30	Robert Steneck and Richard A. Wahle, University of Maine School of Marine Sciences	Vermont
10:00	Break	New Hampshire
<b>CONCURRENT SESSION I</b>		
10:30 am–12:00 pm	<b>Anthropogenic &amp; Environmental Stressors</b>  <i>Rhode Island/Connecticut</i>	<b>Food Web Dynamics</b>  <i>Massachusetts</i>
10:30	An overview of the collapse of the Southern New England lobster stock.  <u>Robert P. Glenn</u> , T. Angell, P. Howell, and K. McKown	Rock crab versus American lobster: Is either critical to coastal ecosystem functioning?  <u>J. Mark Hanson</u> , M. Comeau, and A. Rondeau
10:45	All about M: the 2009 Southern New England lobster stock assessment story.  <u>Penny Howell</u> , K. McKown, and G. Nesslage	Ecosim modeling of ecosystem dynamics for the American lobster in the Gulf of Maine.  <u>Yuying Zhang</u> and Y. Chen
11:00	Update on a long-term (1978-2011) lobster monitoring study in eastern Long Island Sound.  <u>John T. Swenarton</u> and D.F. Landers Jr	Can cod and lobster coexist in the Gulf of Maine?  <u>Marissa D. McMahan</u> , D.C. Brady, D.F. Cowan, J.H. Grabowski, and G.D. Sherwood
11:15	Epizootic shell disease associated with increased mortality in the Southern New England American lobster stock.  <u>Matthew W. Smith</u> , J.D. Shields, D.F. Landers Jr., and J.M. Hoenig	Cannibals by night? Density-dependent feedbacks in the Gulf of Maine's inflated lobster population.  <u>Noah G. Oppenheim</u> and R.A. Wahle
11:30	The Ugly Lobster Database: a flexible, expandable tool for exploring epizootic shell disease.  <u>Thomas W. Dolan III</u> , K. Castro, and J.D. Shields	Linking American lobster abundance and landings with predators, temperature, and climate in the Northwest Atlantic Ocean  <u>Stephanie A. Boudreau</u> , S.C. Anderson, and B. Worm
11:45	Reconciling the past with the future of shell disease.  <u>Michael F. Tlusty</u> , K. Castro, and C. Wilson	Hemolymph biochemistry: an indicator of nutritional status?  <u>M. Ciaramella</u> , <u>A. Battison</u> , and B. Horney
12:00	Lunch	New Hampshire

**Wednesday 28 November**

1:30 pm- 3:00 pm	<b>CONCURRENT SESSION II</b>	
	<b>Anthropogenic &amp; Environmental Stressors</b>	<b>Anthropogenic &amp; Environmental Stressors</b>
	<b>Rhode Island/Connecticut</b>	<b>Massachusetts</b>
1:30	<i>The role of apatite in lobster health.</i> <u>Joseph G. Kunkel</u> , A.M. Shipley, and M.J. Jercinovic	<i>Move it or lose it: contraction of thermal habitat in Buzzards Bay, MA, and implications for the resource.</i> <u>Tracy L. Pugh</u> and R.P. Glenn
1:45	<i>Growth and metabolic rates of early juvenile lobsters Homarus americanus after an acute exposure of the pesticide endosulfan.</i> <u>Dounia Daoud</u> , W. Fairchild, M. Comeau, B. Bruneau, M. Mallet, P. Jackman, K. Benhalima, P. Berillis, and E. Mente	<i>Increased abundance of juvenile lobster (Homarus americanus) correlates with elevated sea surface temperature in the Gulf of Maine.</i> <u>D.F. Cowan</u> and <u>Sara L. Ellis</u>
2:00	<i>Impact on larval development of chronic exposure to a reduced pH environment in the American lobster (Homarus americanus).</i> <u>Josh J. Hall</u> and T.J. Bowden	<i>Effect of a changing thermal regime on settlement dynamics of post-larval American lobster (Homarus americanus) in southern New England.</i> <u>Kelly A. Whitmore</u> and R.P. Glenn
2:15	<i>Alkylphenols have multiple effects on lobster shells, molting and survival.</i> <u>Hans Laufer</u> , M. Chen, B. Baclaski, J. Bobbitt, M. Johnson, Y. Zuo, M. Jacobs, and J. Stuart	<i>Lobster (Homarus americanus) size at maturity in coastal fishing areas in Nova Scotia.</i> <u>Angelica M. Silva</u> , J.M. Tremblay, and D.S. Pezzack
2:30	<i>Monitoring stress during live storage and shipping: gene expression changes of the American lobster as measured by DNA microarray.</i> <u>Spencer J. Greenwood</u> , A.R. Acorn, J. Garland, and K.F. Clark	<i>Mature females looking young: how they modify our perception of size-at-maturity.</i> <u>Julien Gaudette</u> , J.M. Tremblay, S. Waddy, and A. Silva
2:45	<i>American lobster susceptibility to white spot syndrome virus.</i> <u>K. Fraser Clark</u> , A.R. Acorn, S.J. Greenwood, and P.J. Byrne	<i>The influence of optimal habitat on lobster movements in a New England estuary.</i> <u>Thomas G. Langley</u> , J.S. Goldstein, and W.H. Watson III
3:00	<b>Break</b>	<b>New Hampshire</b>
3:30–5:00	<b>Moderated Discussions</b>  <i>Anthropogenic and Environmental Stressors</i> Kathy Castro, Spencer Greenwood  <i>Food Web Dynamics</i> Jonathan Grabowski, Stephanie Boudreau	<b>Vermont</b>

**Dinner on your own**

Thursday 29 November		
7:00 am–5:00 pm	Registration Open	Lobby
7:30	Continental Breakfast	New Hampshire
8:30	Announcements	Vermont
	<b>Plenary Session III: Human-Natural Systems &amp; Ecosystem-Based Management</b>	
9:00	<i>Shifting ecological conditions and the dynamics of American lobster (<i>Homarus americanus</i>) populations.</i> Michael J. Fogarty, National Marine Fisheries Service	Vermont
	<b>Plenary Session IV: Metapopulation Dynamics &amp; Connectivity</b>	
9:30	<i>Connectivity processes and Northwest Atlantic lobsters: academic and management considerations.</i> Lewis S. Incze, University of Maine School of Marine Sciences	Vermont
10:00	Break	New Hampshire
CONCURRENT SESSION III		
10:30 am–12:00 pm	<b>Human-Natural Systems &amp; Ecosystem-Based Management</b>	<b>Metapopulation Dynamics &amp; Connectivity</b>
	<i>Rhode Island/Connecticut</i>	<i>Massachusetts</i>
10:30	<i>Impacts of v-notching on the assessment and management of American lobster stock in the Gulf of Maine.</i> <u>Kathleen Reardon</u> , C. Wilson, J-H. Chang, and Y. Chen	<i>Spatial and temporal variation in larval production of American lobster (<i>Homarus americanus</i>) in Atlantic Canada.</i> <u>Marthe Larsen Haarr</u> , R. Rochette, M. Comeau, B. Sainte-Marie, and J.M. Tremblay
10:45	<i>V-notching in Newfoundland: estimating its effect on size distribution and egg production.</i> K.M. Wilke, <u>Eric J. Pedersen</u> , and R.E. Stanley	<i>Estimates of potential large-scale spatial connectivity of American lobster from a new larval drift model covering most of the species' range.</i> <u>Brady K. Quinn</u> , R. Rochette, and J. Chassé
11:00	<i>The impacts of trap density on catch rates and catch.</i> <u>Carl Wilson</u>	<i>Assessing spatial patterns and patchiness of American lobster (<i>Homarus americanus</i>) settlement in the Bay of Fundy.</i> <u>Guðjón Már Sigurðsson</u> , R. Rochette, and J.M. Tremblay
11:15	<i>Impacts of ghost fishing from American lobster traps.</i> <u>Derek N. Perry</u> , K. Whitmore, and R. Glenn	<i>On the activity levels and movements of juvenile American lobsters (<i>Homarus americanus</i>) in a nursery area: an ultrasonic telemetry study.</i> <u>Bryan Morse</u> and R. Rochette
11:30	<i>Dynamical modeling of complex fish-fisheries interactions.</i> <u>Dominic J. Fitzpatrick</u> and A.J. Pershing	<i>Direct determination of age in crabs, shrimps, and lobsters.</i> <u>Rouf Kilada</u> , B. Sainte-Marie, R. Rochette, N. Davis, C. Vanier, and S. Campana
11:45	<i>Exploring new ways to understand and model the lobster and other fisheries.</i> <u>James Wilson</u> , J. Acheson, Y. Chen, T. Johnson, and R. Steneck	<i>Further test of a new and direct technique to age crustaceans: length-at-age relationships for American lobster from different thermal regimes.</i> <u>Neill Davis</u> , R. Kilada, and R. Rochette
12:00	Lunch	New Hampshire

**Thursday 29 November**

CONCURRENT SESSION IV		
1:30 pm– 3:00 pm	Coupled Human-Natural Systems & Ecosystem-Based Management	Metapopulation Dynamics & Connectivity
	<b>Rhode Island/Connecticut</b>	<b>Massachusetts</b>
<b>1:30</b>	<i>Contrasting effects of size-selective fishing on Atlantic cod and American lobster: a refuge is critical.</i> <u>J. Mark Hanson</u> and M. Comeau	<i>Population structure and the application of reference points to lobster stocks off the Atlantic coast of Nova Scotia and the Gulf of Maine region.</i> <u>John M. Tremblay</u> and D.S. Pezzack
<b>1:45</b>	<i>Long-term sustainability of the American lobster fishery: body size matters.</i> <u>Diane F. Cowan</u>	<i>Evaluate spatial scales for the assessment of American lobster, Homarus americanus, stock in Maine inshore waters.</i> <u>Jui-Han Chang</u> and Y. Chen
<b>2:00</b>	<i>Roles of legal sizes in the management of American lobster (Homarus americanus).</i> <u>Yong Chen</u> , J-H. Chang, Y. Zhang, C. Wilson, and K. Reardon	<i>An exploratory analysis of colour polymorphism in larval American lobster (Homarus americanus): patterns and implications.</i> <u>R.E. Stanley</u> and P.V.R. Snelgrove
<b>2:15</b>	<i>The impact of ovigerous lobster movements on egg development, larval hatch, and settlement.</i> <u>Jason S. Goldstein</u> and W.H. Watson III	<i>Identifying local morphometric patterns in the American lobster (Homarus americanus) using photograph-based measurements and neural networks.</i> <u>Nathan Rycroft</u> , M. Goldberg, and J. Atema
<b>2:30</b>	<i>Lobster as a source of vulnerability and resilience in Maine fishing communities.</i> <u>Anna Henry</u> and T.R. Johnson	<i>Population patchiness reflects a balance of the forces of dispersal and aggregation.</i> <u>Jelle Atema</u> , J. Deppermann, J. Halverson, K. Radcliffe, N. Rycroft, and G. Gerlach
<b>2:45</b>	<i>A historical and regional perspective of fish predation on lobsters in the Gulf of Maine.</i> <u>Jonathan H. Grabowski</u> , G.D. Sherwood, C. Brown, R. Steneck, R. Wahle, and J. Witman	<i>Closing the circle: southern New England's lobster collapse reveals strong signature in the spawner-to-recruit linkage.</i> <u>M. Gibson</u> , <u>Richard A. Wahle</u> , and M.J. Fogarty
<b>3:00</b>	<b>Break</b>	<b>New Hampshire</b>
<b>3:30–5:00</b>	<b>Moderated Discussion Groups</b> <i>Human-Natural Systems &amp; Ecosystem-Based Management</i> Carla Guenther, James Wilson <i>Metapopulation Dynamics &amp; Connectivity</i> Louis Bernatchez	<b>Vermont</b>
<b>5:30</b>	<b>Poster &amp; Awards Reception</b>	<b>New Hampshire</b>

**Friday 30 November**

<b>7:30</b>	<b>Continental Breakfast</b>	<b>Vermont</b>
<b>General Roundtable Discussion/Meeting Recap and Next Steps</b>		
	<i>Summaries of each of the session/roundtable by moderators</i>	
<b>8:30</b>		
	<b>General Discussion</b>	<b>Vermont</b>
	<i>Encouragement of publications</i>	
	<i>Identification of points for inclusion in a 'position paper'</i>	
	<i>Closing remarks</i>	
<b>10:00</b>	<b>Break</b>	<b>New Hampshire</b>
<b>10:30 am- 12:00 pm</b>	<b>Steering Committee Meeting</b>	<b>Connecticut</b>



## **Plenary I: Anthropogenic & Environmental Stressors**

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### **Complex etiologies and the emergence of diseases in lobsters from Long Island Sound.**

Jeffrey D. Shields

Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA, jeff@vims.edu

Over the last decade, several diseases have emerged as health issues in lobsters from Long Island Sound. Neoparamoeba, calcinosis, epizootic shell disease, idiopathic blindness, and hepatopancreatitis were virtually unknown in lobsters until mortalities and obvious signs of disease were observed in the southern New England fishery, prompting further investigations into their etiologies. Anthropogenic and environmental stressors have been implicated as contributing factors in several recent outbreaks of disease in estuarine animals, including lobsters. Such stressors can increase host susceptibility by weakening the host immune defenses or increase the availability, transmission, and severity of pathogens. Stressors such as declining water quality or increased exposure to contaminants can increase rates of disease transmission, increase susceptibility to opportunistic infections, and exacerbate the severity of disease through the suppression of the immune response. Such was the case with the catastrophic lobster mortality observed in western Long Island Sound in 1999-2000. The proximal cause of the mortality was an emergent pathogen identified as *Neoparamoeba pemaquidensis*,

but the ultimate cause was a complex interplay of stressors that resulted in immune suppression: hypoxia, prolonged elevated bottom water temperatures, and potential exposure to pesticides. Environmental and anthropogenic stressors also have been implicated in the etiology of epizootic shell disease. The disease has been characterized as a bacterial dysbiosis of the cuticle with widespread necrosis of the carapace. The effect of epizootic shell disease on individual lobsters has been difficult to determine, but recent declines in landings, and the finding that settlement and recruitment of lobster postlarvae have declined precipitously with the emergence of the syndrome, provide strong evidence of negative effects on the lobster population in Long Island Sound. Other diseases such as idiopathic blindness and hepatopancreatitis are indicators of anthropogenic stressors, but their etiologies remain undetermined. Additional studies such as the “100 lobster” project, grant-funded investigations, fisheries surveys, and ongoing monitoring programs are crucial to our understanding these emerging diseases and their complex etiologies.

## **Plenary II: Food Web Dynamics**

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### **Lobster dynamics in a brave new ocean.**

Robert S. Steneck and Richard A. Wahle

University of Maine School of Marine Sciences, Orono, ME, steneck@maine.edu

Dynamic foodwebs and climate are changing paradigms for lobster ecologists and fishery managers. Here we substantiate the argument that there are no meaningful “equilibrium” conditions with which traditional fisheries management depends, making the goal of a maximum sustainable yield a challenging moving target for the American lobster fishery. *Homarus americanus* evolved in the North Atlantic under conditions of intense predation from large finfish such as Atlantic cod. American lobster’s relatively long brooding period and large larval size results in high per-capita larval and post-larval survival relative to other members of the guild of large crustaceans in the coastal Northwest Atlantic. This, coupled with post-settlement habitat selection for predator refugia, contributes to the species’ ecological

success. However, this region is an extremely low diversity ecosystem prone to booms and busts in consumer populations. In the case of the American lobster, extirpating only few species of large-bodied predators has released past constraints on population growth. The American lobster’s geographic range also straddles one of the steepest north-south gradients in sea temperature on Earth, so climate change can have opposite effects, both stressing and enhancing lobster stocks, over remarkably short distances. Changing conditions are likely to introduce new predators and the risk of disease as warm-water species shift northward. Looking to the future we must expect the unexpected, with new challenges for managing this species into the coming decades of environmental change.

## Plenary III: Human-Natural Systems & Ecosystem-Based Management

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### Shifting ecological conditions and the dynamics of American lobster (*Homarus americanus*) populations.

Michael J. Fogarty

National Marine Fisheries Service, Woods Hole, MA, michael.fogarty@noaa.gov

The American lobster (*Homarus americanus*) has undergone dramatic increases in abundance and yield over the last three decades but is now declining in the southern part of its range. Hypotheses concerning the factors underlying changes in lobster abundance include relaxation of predation pressure by large-bodied benthivores and changes in environmental conditions. Changes in predator populations and large-scale increases in temperature over the last several decades signal the need to consider lobster population dynamics in a broader ecological context. Although the American lobster supports quintessential single-species directed fisheries throughout its

range, it is increasingly clear that management frameworks that ignore biological interactions, environmental/climate change, and the social and economic context cannot fully capture the relevant dimensions necessary for effective lobster management. Folding lobster management into the broader dimensions of “ecosystem-based management” provides one avenue for integration of emerging social and ecological considerations within a more holistic framework. The Northeast region has made progress toward implementation of ecosystem-based management, with options for lobster management within an ecosystem perspective.

## Plenary IV: Metapopulation Dynamics & Connectivity

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### Connectivity processes and Northwest Atlantic lobsters: academic and management considerations.

Lewis S. Incze

University of Maine School of Marine Sciences, Orono, ME, lincze@maine.edu

The exchange of individuals within a population is a central theme in ecology and evolution, and an understanding of the processes is of fundamental as well as practical interest. In marine fauna in general, and fisheries in particular, studies have focused on passive or quasi-passive dispersion during early life stages; on survival and resulting patterns of recruitment as juveniles; and, for mobile taxa, on the movements that take place later in life (dispersive, aggregative, contranant, etc.). Recent developments in tagging and observational technologies and genomic methods, coupled with evolving computational capabilities, enable increasingly detailed studies of these processes for many organisms. In particular, sophisticated biological and environmental models and modeling strategies allow us to “simulate” population

recruitment and production patterns through the entire life history and for multiple generations, but many assumptions in these models remain static. A challenge is the integration of various research results into a holistic understanding of a population over time. Patterns of connectivity, including variability, are now a major consideration in conservation and should be used when evaluating the interacting potential impacts of management and system change. At present, these are scenario evaluations rather than predictions, but they represent a mutually useful nexus between fundamental research and management needs, and knowledge and questions about connectivity and recruitment of lobsters in the Northwest Atlantic can be considered within this context.

## **Concurrent Session I: Anthropogenic & Environmental Stressors**

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### **An overview of the collapse of the Southern New England lobster stock.**

Robert P. Glenn,<sup>1</sup> Tom Angell,<sup>2</sup> Penny Howell<sup>3</sup> and Kim McKown<sup>4</sup>

1. Massachusetts Division of Marine Fisheries, New Bedford, MA, robert.glen@state.ma.us
2. Rhode Island Department of Environmental Management, Jamestown, RI
3. Connecticut Department of Energy & Environmental Protection, Old Lyme, CT
4. New York Department of Conservation, East Setauket, NY

The Southern New England lobster stock historically supported a productive fishery in the coastal and offshore waters from south of Cape Cod to New Jersey. At its peak in 1997, the fishery landed roughly 10,000 metric tons of lobster with an estimated ex-vessel value greater than \$75,000,000. Starting in 2000, commercial landings declined dramatically and reached 30-year lows in 2009. Trends in lobster abundance have followed a consistent pattern regionally across southern New England; abundance was low to moderate in the 1980s, increased dramatically reaching historic high levels in the mid- to late 1990s, and then declined precipitously in the early 2000s. Declines in abundance and commercial harvest have been dramatic, widespread, and persistent. The synchrony of catch and abundance trends across a broad geographic area suggests that large-scale environ-

mental forcing may be at play. American lobsters actively avoid water temperatures greater than 19 °C, and experience physiological stress and increased rates of disease when the water exceeds 20 °C for prolonged periods of time. Starting in 1998, the number of days in which the daily mean water temperature exceeded 20 °C increased substantially. Strong positive anomalies in the number of days in which both the sea-surface and sea-floor water temperature exceeded 20 °C occurred throughout the inshore waters of southern New England. These prolonged periods of warming could have a profound effect on the distribution of adults, natural mortality rates, mating success, settlement dynamics, and rates of disease, and likely have contributed directly to the decline of this stock.

### **All about M: the 2009 Southern New England lobster stock assessment story.**

Penny Howell,<sup>1</sup> Kim McKown,<sup>2</sup> and Geneviève Nesslage<sup>3</sup>

1. Connecticut Department of Energy & Environmental Protection, Old Lyme, CT, penny.howell@ct.gov
2. New York Department of Environmental Conservation, East Setauket, NY
3. Atlantic States Marine Fisheries Commission, Arlington, VA

The Southern New England lobster stock is declining in the face of declining or stable fishery removal rates, indicating an increase in natural mortality has occurred. Mortality likely increased measurably by 1999 when a die-off event occurred in Long Island Sound. However, as is long-held standard practice, the Atlantic States Marine Fisheries Commission stock assessment model was parameterized with a fixed mortality of 0.15 to account for the lobster's life span estimated at 20 years. A temperature stress index was developed based on research into the causes of the Long Island Sound die-off. The stock assessment model was then run with a fixed low mortality of 0.15 for years 1984-1997, and increased mortality values from 10-200% for years 1998-2007, which

bracketed the percentage increase in the temperature stress index seen before and after the die-off. Model fit to observed abundance trends and length frequency data was then determined by comparison of negative log likelihood values. The model which assumed mortality (M) in later years was 1.9 times the base case ( $M = 0.285$ ) best fit the observed data. Retrospective pattern observed in the traditional, constant ( $M = 0.15$ ) run more than halved with incorporation of a biphasic mortality. This result, in combination with likelihood comparison results, indicates that an increasing trend in mortality is supported by the data and should be incorporated into future assessments.

### **Update on a long-term (1978–2011) lobster monitoring study in eastern Long Island Sound.**

John T. Swenarton and Donald F. Landers Jr.

Millstone Environmental Laboratory, Dominion Resource Services, Waterford, CT, john.t.swenarton@dom.com

A lobster monitoring study has been conducted since 1978 as part of permit requirements for the operation of an electric generating station (Millstone) located in Waterford, Connecticut, eastern Long Island Sound. The adult trap and tag survey showed lobster abundance peaked in the 1990s, but has since declined to low but relatively stable levels. A similar pattern was observed in our trawl survey catches and eastern Long Island Sound commercial landings. The decline in lobster abundance over the last decade was unrelated to power

station operations, but corresponded with increased frequency of diseased and dead lobsters, a natural rise in ambient seawater temperature, and a decline in seawater pH. Shell disease has become prevalent since the late 1990s, particularly with egg-bearing females, and has resulted in reduced growth per molt and higher mortality. The higher susceptibility of egg-bearing females to shell disease may account for reduced densities of larvae observed in entrainment samples collected over the same time period.

## Concurrent Session I: Anthropogenic & Environmental Stressors

### Epizootic shell disease associated with increased mortality in the Southern New England American lobster stock.

Matthew W. Smith,<sup>1</sup> Jeffrey D. Shields,<sup>1</sup> Donald F. Landers Jr.,<sup>2</sup> and John M. Hoenig<sup>1</sup>

1. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, VA, mws212@vims.edu

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In the last decade the American lobster stock off southern New England has experienced a dramatic decline. Research and stock assessment models have indicated that low recruitment and elevated natural mortality likely have played a critical role in the decline. Coincident with the decline was the onset of epizootic shell disease, which is now found at prevalence levels as high as 20-30%. Understanding the role shell disease has played in the population decline is an important step in the development of management plans aimed at rebuilding the stock. Data on shell disease severity and prevalence were recorded as part of a long-term tagging study conducted in eastern Long Island Sound. We used logistic regression to estimate disease-associated mortality by disease severity state, sex, and reproductive status (ovigerous or non-ovigerous). Our

analysis shows significant mortality associated with epizootic shell disease and suggests that natural mortality rate for the Southern New England stock has more than doubled from the previously assumed rate. This study also shows that ovigerous females have a higher mortality rate than non-ovigerous females, and this likely contributes to the declining population. Shell disease likely contributes to a reduction in reproductive output through lost clutches, as well as reducing spawning stock biomass through disproportionately elevated female mortality. These findings corroborate the stock assessment's suggestion that natural mortality rate has risen in the Southern New England stock and identifies important linkages between disease and stock-recruitment relationships in the region.

### The Ugly Lobster Database: a flexible, expandable tool for exploring epizootic shell disease.

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Epizootic shell disease in the American lobster (*Homarus americanus*) has been devastating to the southern New England fishery and is increasingly prevalent in other regions. In response, "The 100 Lobster Project" was initiated to understand the roles of the environment, pathogens, and pollutants in the ecology and etiology of the disease. Samples of carapace, tissues, and hemolymph were taken from more than 100 lobsters collected from waters of Rhode Island and Maine. Tissues were sent to collaborating laboratories as well as saved at -80 °C for future studies. A data repository contains information regarding lobster status, pathology,

and metals content, and also provides a portal to the tissue bank and photo library. The database can be used to analyze relationships, such as the relationship of tissue metal concentrations and histopathological markers to disease severity. The relational data model allows for maximum flexibility for expansion and future development; additional data on histology, bacterial communities, and molecular information will be integrated as funding becomes available. The SQL server is web-accessible and currently resides at <http://www.vims.edu/research/departments/eaah/lobsterdisease/>.

### Reconciling the past with the future of shell disease.

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The emergence of epizootic shell disease in American lobsters *Homarus americanus* in the southern New England area, has presented many new challenges to understanding the interface between disease and fisheries management. A special New England Lobster Shell Disease Initiative completed in 2011, explored many of the causative and correlative factors for shell disease. This work will ideally form the basis for epidemiological tools that can be used to elucidate the interactions between fisheries management and disease. Here, a conceptual model originally developed for human-parasite interactions is applied to lobster shell disease as a means to unify the broad results generated by the

NELSDI. The timing for a conceptual understanding of the epidemiology of shell disease is critical as last year (2011) in Maine, while still at a low prevalence (1 shell disease observation every 500 lobsters), shell disease is twice as abundant as it has been in previous years. This is of great concern given the importance of the Maine harvest to the overall health of the fishery. The development of a conceptual epidemiological model will be the basis for continued work on this problem. Ideally it will help managers and biologists in Maine create an effective strategy for monitoring the growth of this disease, and in the best case, helping them to limit the impact of this disease on lobster populations and the fishermen.

## **Concurrent Session I: Food Web Dynamics**

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### **Rock crab versus American lobster: Is either critical to coastal ecosystem functioning?**

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Stomach contents, diet overlap, and predator occurrence in stomachs were compared for rock crab (*Cancer irroratus*) and American lobster (*Homarus americanus*) inhabiting Northumberland Strait. Rock crab had a broad diet consisting of fish, molluscs, Crangon shrimp, rock crab, and polychaetes. Lobster had a narrow diet consisting of rock crab, old lobster carapaces, echinoderms, and fresh lobster. About 30% of the lobster diets, and 8% of the rock crab diet, were attributed to scavenging. Diet overlap was low. The principal source of mortality for lobster is the fishery. Lobster was a trace item in all fishes examined ( $n = 26,000$ ) except the rare shorthorn sculpin (*Myoxocephalus scorpius*). Rock crab larvae comprised >7% of diets of Atlantic mackerel (*Scomber scombrus*), gaspereau (*Alosa pseudoharengus*), and Atlantic

herring (*Clupea harengus*). Small (<40 mm carapace width) rock crab comprised 11-43% of the prey biomass of cunner (*Tautogolabrus adspersus*), longhorn sculpin (*M. octodecemspinosis*), winter skate (*Raja ocellata*), and shorthorn sculpin. Rock crab and lobster were trace items in the diets of Atlantic cod (*Gadus morhua*) and white hake (*Urophycis tenuis*). Rock crab and lobster (>60 mm carapace width or carapace length, respectively) were all but immune to non-human predators and, perhaps, cannibalism. Loss of American lobster from the Northumberland Strait ecosystem would mainly affect humans dependent upon this fishery. In contrast, loss of rock crab could greatly alter the food web, result in loss of a moderate fishery for rock crab, and likely result in the loss of the fishery for American lobster.

### **Ecosim modeling of ecosystem dynamics for the American lobster in the Gulf of Maine.**

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The Gulf of Maine American lobster supports one of the most economically valuable commercial fisheries in the northeastern United States. The Gulf of Maine ecosystem has experienced a great change over the last two decades, switching from a groundfish-dominated system to a crustacean-dominated system. An evaluation of lobster ecosystem dynamics can help identify possible causes of such a change and improve our understanding of interactions between lobster and other species in the same ecosystem. The objective of this study is to evaluate impacts of different management scenarios for American lobster and Atlantic cod (*Gadus morhua*) fisheries on the dynamics of American lobster (*Homarus americanus*) ecosystem in the Gulf of Maine. We developed a 24-group Ecosim model to quantify the dynamics of the American lobster ecosystem in the Gulf of Maine

from 1985 to 2007. We also developed a Monte Carlo simulation approach to incorporating uncertainties for 40 most sensitive vulnerabilities. We found that the lobster ecosystem dynamics could be generally well simulated using the Ecosim model compiled in this study. A high fishing mortality in cod could result in high lobster stock biomass, suggesting that higher fishing pressure on cod in the 1980s might have contributed to the high lobster biomass in recent years. Increasing the fishing mortality for lobster from 0 to 1 year<sup>-1</sup> would have led to decrease in lobster biomass. The change in the fishing mortality of cod and adult lobster would also affect the biomass dynamics of other groups, indicating that the dynamics of Atlantic cod and American lobster stocks might be important factors that led to changes in the Gulf of Maine lobster ecosystem in the last two decades.

## Concurrent Session I: Food Web Dynamics

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### Can cod and lobster coexist in the Gulf of Maine?

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Historically the nearshore Gulf of Maine fishery ecosystem was very different than it is today; archeological records coupled with fishery effort and landings data over the past few centuries suggest that large predatory groundfish were once dominant, and crustaceans less abundant. Today the most economically important species in the Gulf of Maine ecosystem is the American lobster (*Homarus americanus*), whose landings have more than quadrupled in the last two decades (1990-2010). Increased lobster landings have coincided with the collapse of groundfish fisheries such as Atlantic cod (*Gadus morhua*). Many have speculated that the relationship between lobster and groundfish landings may be causative and not simply correlative. The mechanism they argue is that a reduction in abundance of large predatory ground-

fish may have resulted in lower lobster predation rates and thereby increased lobster foraging areas. In order to explicitly examine this proposed mechanism we used fine-scale acoustic telemetry within a large (approximately three to six acres) enclosed embayment to test the hypothesis that the presence of a large fish predator, Atlantic cod, would induce lobsters to decrease movement and seek refuge. The addition of cod into the embayment significantly reduced the distance lobsters traveled from their shelters, reduced home range area, and reduced the frequency of foraging outside of shelter areas. The observed predator-induced reductions in movement may help explain why lobster stocks in the Gulf of Maine have exponentially increased since the collapse of many groundfish stocks.

### Cannibals by night? Density-dependent feedbacks in the Gulf of Maine's inflated lobster population.

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As large predatory groundfish have been depleted in the Gulf of Maine, American lobster populations have reached historic highs, making density-dependent feedbacks more likely. We conducted predation experiments at multiple sites in midcoast Maine, where lobsters are especially abundant, to document day-night differences in the types and frequency of predator encounters. We conducted separate day and night deployments of tethered lobsters under time-lapse video surveillance with infrared illumination during the nighttime trials. Supplemental tethering trials without video surveillance provided further quantitative information on diel and

size-specific predation patterns. We found that crabs and fish were the most common predator during the day, but that lobsters prevailed at night, with larger lobsters consistently dismembering and consuming smaller, tethered conspecifics. To our knowledge, these are the first documented reports of cannibalism in the American lobster outside of captivity. Unexpectedly, we measured higher predation rates at night than during the day, suggesting nocturnal interactions with conspecifics may now play a significant role in lobster population regulation in a world where predatory fish are rare.

## abstracts

### Concurrent Session I: Food Web Dynamics

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#### Linking American lobster abundance and landings with predators, temperature, and climate in the Northwest Atlantic Ocean.

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Over the past three decades, the abundance of American lobster (*Homarus americanus*) in the Northwest Atlantic Ocean has undergone large changes, the driving mechanisms of which have not yet been examined across the species' range. Here we analyzed all available time-series data of lobster abundance and landings, together with data on the abundance of their teleost and elasmobranch predators, as well as changes in temperature and climate through mixed-effects models across nine regions of Canada and the U.S. in the Northwest Atlantic. This analysis covered the entire range of the species, and addressed competing hypotheses about the bottom-up (climate, temperature) versus top-down (predation, fishing) regulation of lobster populations. Results offered some support for the predation hypothesis in regions other than the southern Gulf of St. Lawrence and Georges

Bank. Independently of region-specific predation effects, there was broad support for a climate effect on lobster recruitment and early development across all regions. This was consistent with a large-scale influence of the North Atlantic Oscillation Index on lobster early life stages, as the strongest effect was found at lag six to eight years. The mechanism of this effect remained unclear, as changes in temperature did not emerge as a major predictor of lobster abundance and landings. Likewise, fishing effort appeared to be following lobster abundance, rather than regulating abundance in a consistent way. This analysis provides evidence that predation and climate both play some role in regulating lobster abundance in the Northwest Atlantic, but that they act on different life stages in the population.

#### Hemolymph biochemistry: an indicator of nutritional status?

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Hemolymph biochemistry profiles were examined as a potential non-lethal means to assess tissue energy reserves (lipid and glycogen) in the American lobster (*Homarus americanus*). Energy reserves are known to fluctuate over the molt cycle in the American lobster and other crustaceans. Tissue samples (hepatopancreas, crusher claw, pincher claw, and tail muscle) were collected from 88 lobsters fished out of Georgetown, Prince Edward Island (LFA 26A) from May to September 2009 and 2010. Tissue lipid, glycogen, and water

content were determined and then compared to hemolymph plasma biochemistry parameters to identify a parameter(s) that might be a useful indicator of nutritional status. Lipid was the more abundant energy reserve and was found predominantly in the hepatopancreas. Correlations between hemolymph parameters and hepatopancreas lipid content were affected by sex and molt stage of the lobster. The best correlations were found for total protein, cholesterol, and triglyceride concentrations in intermolt male lobsters.

## Concurrent Session II: Anthropogenic & Environmental Stressors

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### The role of apatite in lobster health.

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There is debate over calcium carbonate and phosphate forms and functions in the American lobster (*Homarus americanus*) cuticle. In 2005, we began a series of studies to examine the mineral properties of the lobster shell in normal and shell-diseased individuals. In addition to calcium carbonate mineral forms, we identified four focal locations of minerals with carbonate apatite consistent chemistry. The locations

and potential roles of these mineral deposits are consistent with the cuticle's role in protecting the lobster from physical and microbial attack. They represent potential targets for shell disease strategies. The erosion of mineral may be the first step in lesion formation, which likely starts at imperfections of the cuticle that we argue may be mineral-based.

### Growth and metabolic rates of early juvenile lobsters (*Homarus americanus*) after an acute exposure of the pesticide endosulfan.

Dounia Daoud,<sup>1</sup> Wayne Fairchild,<sup>2</sup> Michel Comeau,<sup>2</sup> Benoit Bruneau,<sup>3</sup> Martin Mallet,<sup>1</sup> Paula Jackman,<sup>4</sup> Kadra Benhalima,<sup>2</sup> Panagiotis Berillis,<sup>5</sup> and Elena Mente<sup>5</sup>

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Chemicals in the environment during critical periods could potentially affect the physiology of the economically valuable American lobster (*Homarus americanus*). Endosulfan (Thiodan™) is a broad-spectrum organochlorine insecticide widely used in agricultural areas within the Gulf of St. Lawrence that significantly effects the survival and growth of lobster larvae based on acute exposure studies. To detect more subtle physiological effects of an acute (96-h, 0.1 µg L<sup>-1</sup>) sub-lethal level of endosulfan exposure on early juvenile lobsters, metabolic rates, growth, and the tissue structure of the hepatopancreas were investigated for animals that molted following the exposure. The standard and maximum metabolic rates were not significantly affected, but their differential, defined as the metabolic scope (MS) was significantly decreased by 25% for exposed animals. Lobster growth and survival were not affected. For the exposed lobsters, minor alterations of the digestive

cell structures were observed with the hypertrophy of nuclei and loss of basophilic character for F-cells, and larger vacuoles and a loss of the cell shape for B-cells compared to the controls. These results suggest that the drop in MS for exposed lobsters could have consequences in terms of survival in the wild by impairing their abilities to find shelter, food, or protect themselves from predators. The growth and survival in laboratory conditions suggests that lobster may adjust their metabolism to pollutant exposure by maintaining a positive energy balance with some compensatory mechanisms; however, this may not be possible in their natural environment. This study suggests that conclusions based solely on lethal toxicity assays could be misleading for sublethal effects of pollutants on marine organisms, which could be investigated more thoroughly using an integrated approach based on physiological indicators.

## **Concurrent Session II: Anthropogenic & Environmental Stressors**

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### **Impact on larval developmental of chronic exposure to a reduced pH environment in the American lobster (*Homarus americanus*).**

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Climate change driven by anthropogenic pollution is an increasing problem. Federally-supported reviews indicate that ocean acidification could result in a drop in the pH of the North Atlantic from a current pH of just under 8.2 to nearly 7.9 by 2050. This study investigated the difference in development of newly hatched larvae until 90 days post-hatch when

exposed to these levels of acidity. Studies included: morphological analysis, carapace calcification, and molecular expression of immune parameters. The results indicate that chronic exposure can have a detrimental impact on larval development.

### **Alkylphenols have multiple effects on lobster shells, molting, and survival.**

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Alkylphenols, derived from the manufacture and use of plastics, detergents, and antioxidants, are present in the aquatic environment as a result of their production, use, and disposal. Scientists are concerned because of the toxicity and estrogenic endocrine-disrupting activity of alkylphenols. As many as 48% of lobsters in New England were contaminated with at least one or up to six alkylphenolic compounds in their blood or tissues, at concentrations up to 1-2 µg/g wet weight. The compounds are: 2-t-butyl-4-(dimethylbenzyl) phenol (Comp. 1); 2,6-bis(t-butyl)-4-(dimethylbenzyl) phenol (Comp. 2); 2,4-bis-(dimethylbenzyl) phenol (Comp. 3); 2,4-bis (t-butyl)-4-(dimethylbenzyl)-6-butyl-phenol (Comp. 4); 4-cumylphenol; and bisphenol A (BPA). With in vitro incorporation of C14-tyrosine or C14-Comp. 3, cold BPA and Comp. 3 competed more effectively than cold tyrosine, which normally crosslinks proteins, and functions in shell hardening,

weakening lobster shells, possibly making them more susceptible to microbial invasion. Administrating Comp. 3 or BPA (5 or 10 ng/per day/larva) in food, resulted in increased mortality (69% controls survived vs. 13-14% and 16-21% for Comp. 3 and BPA, respectively). Methyl farnesoate (MF) treatment, which has juvenile hormone activity in lobsters, resulted in larval intermediates at metamorphosis. Untreated controls metamorphosed into juveniles by 19 days, while treated survivors (n = 35) metamorphosed into intermediates (n = 22 or 40-88% depending on treatment) by hormone disruption. Molting and metamorphosis were delayed by three to four days in treated larvae. In conclusion, alkylphenols are major pollutants in the marine environment. They are toxic endocrine disruptors, interfere in lobster survival, molting, and metamorphosis, and have multiple mechanisms of action, adversely affecting health problems for lobsters and humans.

## Concurrent Session II: Anthropogenic & Environmental Stressors

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### Monitoring stress during live storage and shipping: gene expression changes of the American lobster as measured by DNA microarray.

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The American lobster fishery is the most economically important commercial fishery in Atlantic Canada, where the annual landed value exceeds \$600 million. Quality live lobsters demands a premium price but lobsters face many anthropogenic and environmental stressors during the journey from natural ocean habitat to the consumer. Companies with live storage of lobsters routinely suffer losses of 5-15% due to mortality. This study measured changes in gene expression

using a combination of a lobster-specific DNA microarray and complementary RT-qPCR as a means of discovering new information about the physiological stresses encountered by lobsters during live storage and shipping. Numerous metabolic and stress-related genes were differentially regulated during live-storage and shipping that provide insight into the physiological stresses as the lobster moves through the chain of custody from ocean to plate.

### American lobster susceptibility to white spot syndrome virus.

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White spot syndrome virus (WSSV) has devastating consequences to infected crustaceans; shrimp routinely experience mortality within three to 10 days post-infection. Numerous experimental infection trials have shown that many crab, lobster, and shrimp species around the world are susceptible to WSSV infection. Hundreds of Atlantic Canada communities rely on the American lobster (*Homarus americanus*) fishery for their sustainability, and the consequences of a WSSV outbreak in the Atlantic Canada lobster population could be economically devastating. WSSV introduction into Atlantic Canada could potentially come from the improper disposal of infected commodity shrimp, mixing of WSSV-infected South Carolina shrimp populations with American lobster populations due to global warming, or the introduction of infected crustaceans in shipping ballast water. WSSV from infected shrimp was injected into *H. americanus*. Multiple

diagnostic tests were used to determine if WSSV has an effect on *H. americanus*, including circulating haemocytes monitoring, histology, electron-microscopy, quantitative PCR, and RT-qPCR. In addition to static temperature trials, we conducted pilot experiments in which WSSV-injected lobsters were held at different temperatures to determine if, as in shrimp, WSSV infections are restricted to certain temperature ranges. Our preliminary results indicate that WSSV is capable of replicating within many lobster tissues and results in eventual mortality of an infected lobster. Additionally, the susceptibility of *H. americanus* may be dependent on water temperature. This work has generated, and characterized, the first ever viral disease model of the American lobster, which will facilitate significant advances in our understanding of lobster immunology.

## abstracts

### Concurrent Session II: Anthropogenic & Environmental Stressors

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#### Move it or lose it: contraction of thermal habitat in Buzzards Bay, Massachusetts, and implications for the resource.

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Buzzards Bay, Massachusetts, used to support a thriving inshore lobster fishery, but since peaking in the late 1990s has experienced dramatic declines and subsequent attrition in the industry. In an effort to maintain viable catch rates, the remainder of the fleet has shifted effort offshore to deeper waters, presumably following the resource. Data from Massachusetts Division of Marine Fisheries surveys indicate that inshore lobsters appear to be concentrated near the mouth of Buzzards Bay and Vineyard Sound, where deeper waters penetrate into the embayment. Much of the upper part of Buzzards Bay experiences extremely warm summer water temperatures, often in excess of 20 °C for long periods of time. These extremely warm summer temperatures may explain the low catch rates observed throughout much of

Buzzards Bay, and may be a contributing factor to the decline of the resource in the region. Lobsters may be leaving the shallower areas to seek out deeper, cooler waters, which could concentrate the population over a smaller spatial area and actually temporarily increase fishing efficiency. We examined temperature trends in Buzzards Bay during time periods of peak landings and the more recent depressed conditions, and, based on lobster thermal preferences and physiological tolerances, we developed a thermal contour map of the area to illustrate changes in thermal habitat over time and the implications of this reduction in available near-shore habitat from the perspectives of adult and early benthic phase lobsters.

#### Increased abundance of juvenile lobster (*Homarus americanus*) correlates with elevated sea-surface temperature in the Gulf of Maine.

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The Lobster Conservancy's Juvenile Lobster Monitoring Program is developing a time series of abundance and distribution of post-larval and early benthic phase American lobster (*Homarus americanus*) along the Gulf of Maine coastline. The census began at Lowell's Cove in Casco Bay, Maine, in 1993 and represents the first year-round monthly sampling of lobster abundance. At this site, strong seasonal cycles in juvenile lobster abundance correspond with mean monthly sea-surface temperature. Moreover, between 1993 and 2010

mean annual density of juvenile lobsters is strongly correlated with mean annual sea-surface temperature at Boothbay Harbor ( $r = 0.80$ ,  $p = 0.001$ ). During this period, mean annual sea-surface temperature increased nearly 3 °C (8.5 to 11.3 °C) and lobster density increased nearly five-fold (0.8 to 3.9 lobsters/m<sup>2</sup>). From year to year, mean annual lobster density and sea-surface temperature followed similar patterns of fluctuation.

#### Effect of a changing thermal regime on settlement dynamics of post-larval American lobster (*Homarus americanus*) in southern New England.

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Young-of-the-year (YOY) settlement is at a record low in southern New England Lobster Management Area 2 (LMA 2). The stock is in poor condition with abundance and yield at or near time-series lows; however, the decline in settlement was observed prior to reductions in adult abundance and spawning stock biomass. Timing of the settlement decline suggests that environmental factors may be altering early life history processes. For example, increases in water temperature since the late 1990s have been coincident with changes in the spatial distribution of ovigerous females. This may be altering larval release locations and transport patterns. In 2009 and 2010, we investigated possible mechanisms for settlement decline in LMA 2. Our objectives were to examine

the relationship between past and present concentrations of ovigerous females and YOY settlement, determine the current geographic distribution of YOY settlement, and assess habitat suitability in nearshore waters of LMA 2. A suite of post-larval settlement collectors, satellite-tracked drifters, temperature monitors, and air-lift sampling efforts were used to capture information on lobster larval delivery and post-larval settlement conditions in the Rhode Island and Massachusetts portions of LMA 2. Results elucidate factors influencing the decline and lack of recovery of the Southern New England lobster stock and support the conclusion that the stock is experiencing recruitment failure.

## Concurrent Session II: Anthropogenic & Environmental Stressors

### Lobster (*Homarus americanus*) size at maturity in coastal fishing areas in Nova Scotia.

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Knowledge about the size at which female lobsters reach sexual maturity is an important consideration for the sustainable management of lobsters. Lobster maturity information for Nova Scotia, Canada, fishing grounds is scarce, older than 20 years, or not available. In collaboration with the lobster fishing industry, it was possible to evaluate maturity of female lobsters in four areas off the Atlantic coast of Nova Scotia. Selected inshore grounds were: Canso (2008-2011), Tangier (2010-2011), Port Mouton (2009-2011), and Lobster Bay (2010-2011). Maturity status of female lobsters was assessed by cement gland staging from May to June in Canso and Tangier, and from May to August in Port Mouton and Lobster Bay, for each respective year. Overall, a greater pro-

portion of legal size lobsters (>82.5 mm carapace length) were mature in eastern Nova Scotia. This was particularly the case for Canso (range 41-100%) where maturity was expressed earlier in the season than at any other location. Tangier had a similar proportion of mature legal lobsters, albeit slightly reduced (38-84%). Fewer mature legal female lobsters were observed in areas southwest of Halifax, off Port Mouton (10-59%) and Lobster Bay (6-51%). Maturity among sub-legal lobsters (<82.5 mm) was observed more frequently in Canso (32-92%) than Tangier (5-22%), Port Mouton (0-5%), and Lobster Bay (0-14%). Differences in the timing of expression of maturity could be related to differences in the seasonal timing of environmental events.

### Mature females looking young: how they modify our perception of size-at-maturity.

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Lobster size at onset of maturity (SoM) was last estimated for Grand Manan from animals collected in the early 1980s, when the 50% SoM (SoM50) was estimated at 108.1 mm carapace length (Campbell and Robinson 1983). A shift to smaller berried females and other observations indicate females are now maturing at smaller sizes, but there are uncertainties about the historical estimates. Using unpublished data from 1978-79 and current data, we re-evaluated the earlier estimates using cement gland development and ovary stages. SoM50 for the 1978-79 dataset were similar (approximately 99.8 mm carapace length) but the slope of the maturity ogives were drastically different. Presence of large, "false immature" females (i.e., non-ovigerous females with no cement gland but mature ovaries) produced the diver-

gence. These "false immature" females in 1978-79 may have resulted from severe nemertean infestations and we suspect this resulted in the earlier high estimates for SoM50. In 2011, SoM50 was estimated at 91.4 mm carapace length for Grand Manan and large immature females were not a factor. However, in other regions, the presence of large immature females did affect the SoM50 estimates. In these cases, mating failure may be responsible for the presence of large immature females. Future SoM studies using cement gland development should evaluate the potential effect of false immature females. Despite the evidence that the earlier study overestimated SoM, female lobsters are maturing at smaller sizes now. Causes for the shift have not been examined yet.

### The influence of optimal habitat on lobster movements in a New England estuary.

Thomas G. Langley, Jason S. Goldstein, and Winsor H. Watson III

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Previous studies of seasonal migrations of lobsters (*Homarus americanus*) in the Great Bay Estuary, New Hampshire, have shown movement toward the Gulf of Maine during the fall and winter, and up into the estuary in the spring. It has been proposed that these movements are primarily responses to seasonal fluctuations in temperature and salinity. Over two years, we used ultrasonic telemetry to track lobsters and determine whether temperature and salinity affected the movements of immature lobsters (n = 20) differently from those of adults (n = 30). However, we found that the majority of lobsters failed to move significant distances. Instead, they either remained near where they were released,

or they moved until they reached a certain location within the estuary. We offer three explanations for this pattern. First, storms and the associated drops in salinity had reduced the population density in previous years. Second, there were no abnormal seasonal temperatures, or major drops in salinity during this study. Third, dive surveys revealed that lobsters' preferred location was characterized by optimal habitat, similar to what is present along the New Hampshire coastline. Therefore, we propose that the presence of optimal habitat might have as strong an influence on the tendency of lobsters to migrate as seasonal fluctuations in temperature and salinity.

## abstracts

### Concurrent Session III: Human-Natural Systems & Ecosystem-Based Management

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#### Impacts of v-notching on the assessment and management of American lobster stock in the Gulf of Maine.

Kathleen Reardon,<sup>1</sup> Carl Wilson,<sup>1</sup> Jui-Han Chang,<sup>2</sup> and Yong Chen<sup>2</sup>

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The practice of v-notching to protect reproductive female lobsters has been considered a cornerstone of lobster conservation in Maine since the 1920s. Since 1985, the Maine Department of Marine Resources has monitored the characteristics of the discards of the lobster fishery through an at-sea sampling program. Over the past 20 years, the program has recorded that nearly 30% of all legal sized female lobsters are returned on a daily basis due the presence of a v-notch. While the lobster landings have more than tripled in the past two decades, the v-notch rates of berried females have stayed consistent. Impacts of v-notching on the dynamics of lobster stock are, however, not quantified. In this study,

we quantify the historical patterns of v-notched lobsters and berried females and assess the implications of these discards in the lobster stock assessment. We evaluate importance of developing reliable estimates of v-notching on the current length-based stock assessment model. As the inshore lobster resource is heavily pursued by the fishery, v-notching remains one of the only tools in place designed to increase reproductive potential and reduce fishing mortality. Using a length-structured stock projection model, we quantify impacts of v-notching on the dynamics of lobster stock in the Gulf of Maine.

#### V-notching in Newfoundland: estimating its effect on size distribution and egg production.

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V-notching has been used in Newfoundland since the mid-1990s as a conservation measure aimed at increasing egg production. However, as v-notching is voluntary and there has been no comprehensive effort to determine how broadly it has been adopted, it is difficult to know how effective it has been at increasing the stock of large reproductive lobsters. Examining how the stock-structure of notched and non-notched females varies among Newfoundland fishing areas may give us some idea of the impact v-notching is having on egg production, as well as how variable the effect is among fishing communities. We examined data on size distributions of both v-notched and non-notched females from 15

Lobster Fishing Areas (LFAs) in Newfoundland that have adopted voluntary v-notching of ovigerous female lobsters. We fit mixed-effect models to this data to determine the average increase in carapace length from v-notching, as well as the amount of inter-LFA variability in the size of this effect. Additionally, using prior data on the relationships between carapace length and maturity, the percentage of mature lobsters that are ovigerous, and egg production by ovigerous lobsters in Newfoundland fisheries, we estimated to what degree v-notching is expected to lead to increased egg production, and to what extent this will vary between LFAs.

#### The impacts of trap density on catch rates and catch.

Carl J. Wilson

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A primary management tool for the U.S. lobster fishery has been imposing limits on traps as a measure of effort control, yet the relationship between trap numbers and catch is poorly understood. Thus, the effectiveness of this input-control management strategy in regulating exploitation rates is not well understood. A collaborative trapping experiment was conducted in the waters surrounding Monhegan Island, Maine, during September and October 2005, to test the impacts of trap density on catch. Eight 1 km<sup>2</sup> trapping areas

were established with three assigned densities of traps (50, 150, and 500 traps km<sup>2</sup>). Initial results indicate that trap density was inversely related to catch rates and the cumulative catch in 150-trap areas was within 15% of 500-trap areas. This result indicates that significant trap density reductions could increase catch rates and not impact the total catch, and suggests implications for effort control limits and development of a new management strategy.

## Concurrent Session III: Human-Natural Systems & Ecosystem-Based Management

### Impacts of ghost fishing from American lobster traps.

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More than four million lobster traps are fished in the American lobster fishery, with around 400,000 traps set in Massachusetts waters. Despite the large scale and high value of this fishery, little information exists on the amount of lobster traps annually lost or how long these “ghost traps” continue to fish. Legally required degradable escape panels are believed to reduce capture and mortality of lobsters, but substantial loss of yield to the lobster fishery may occur even if ghost traps continue to fish short-term. “Missing catch” may also undermine our ability to model lobster population dynamics. In May 2010, we set and “abandoned” two baited six-pot trawls near Manomet Point, Cape Cod Bay

and Penikese Island, Buzzards Bay. Additional trawls were set at each location in November of 2010 and May of 2011. Divers surveyed the gear twice a month and recorded trap condition, species catch composition, biological information from lobsters, and mortality for trapped animals. Animals remained in the trap to mimic “re-baiting.” Traps set in Cape Cod Bay actively fished for an average of 277 days after set and all were disabled after 502 days. After more than 700 days, 94% of the gear set in Buzzards Bay in 2010 is still fishing. Mortality rates for lobsters were between 0.011 and 0.017 per trap per day, based on location and vent shape.

### Dynamical modeling of complex fish-fisheries interactions.

Dominic J. Fitzpatrick and Andrew J. Pershing

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Dynamics in fishery ecosystems are forced by natural interactions between species, oceanographic processes, and human activity through fishing. We use a dynamical modeling approach to explore linkages between American lobster, Atlantic herring, and Atlantic cod populations in the Gulf of Maine. An initial model of the natural system demonstrates simple predator-prey interactions among the three populations (cod prey on lobsters and herring, herring prey on larval cod). A second model incorporates the impact of fish-

ing on the three species under various fishing mortalities and fleet dynamics. This model also includes an important connection between lobster and herring: herring are used as bait in the lobster fishery and herring bait is now an important food source for lobsters. We compare the fish populations under a dynamic fleet of fishermen who are able to switch between fisheries, and a static fleet restricted to one species. This is important for fishery managers attempting to move toward an ecosystem-based approach.

### Exploring new ways to understand and model the lobster and other fisheries.

James Wilson, James Acheson, Yong Chen, Teresa Johnson, and Robert Steneck

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The point of management is to create rules that restrain fishermen's behavior in a way that sustains the fishery. For almost all fisheries, this means rules that control total catch. This requires predicting the change in the size of the future stock in response to a change in the total catch today. Where this approach has been followed the results have been very poor. From a scientific point of view, it can be argued that the kinds of long-run quantitative predictions this approach requires may not be possible because of the complexity of ocean ecosystems. The lobster fishery has not pursued this approach and, compared with other fisheries, has been very successful. The rules governing fishing attempt to maintain basic biological functioning rather than numbers. The cur-

rent very abundant lobster population is at least partly the result of poor management in other fisheries. However, it is undoubtedly the case that the rules in the lobster fishery have prevented its depletion. We believe the principal reason these rules work is because they incorporate the knowledge of fishermen, scientists, and managers. The fishery is a very good example of self-governance in action. We performed some initial modeling work aimed at understanding why the lobster fishery works. The models are a radical departure from the usual approach: they have their roots in computer science, evolution, ecology, anthropology, and economics; and they emphasize the importance of individual and collective learning and of self-governance.

## **Concurrent Session III: Metapopulation Dynamics & Connectivity**

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### **Spatial and temporal variation in larval production of American lobster (*Homarus americanus*) in Atlantic Canada**

Marthe Larsen Haarr,<sup>1</sup> Rémy Rochette,<sup>1</sup> Michel Comeau,<sup>2</sup> Bernard Sainte-Marie,<sup>3</sup> John M. Tremblay,<sup>4</sup> and industry partners

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The “Lobster Node” of the Natural Sciences and Engineering Research Council of Canada Capture Fisheries Research Network comprises a five-year collaborative project between lobster harvesters, academics, and government scientists on the question of lobster stock structure and connectivity in Atlantic Canada. The project involves five research components, four of which are based on stages of the life cycle: larval production, larval drift, larval settlement, and movement of juveniles and adults. The fifth component aims to elucidate genetic stock structure. The objective of the first component is to estimate spatiotemporal variation in larval production based on the abundance and characteristics of berried females. Data are being collected by fishermen on the abundance, size, clutch quality, and hatch time of berried females with the objective of one fisherman every 50-75 km

of coastline sampling weekly throughout the fishing season. Data collected in 2011 suggest that among areas sampled, berried female abundance, estimated by catch-per-unit-effort, was highest around eastern Cape Breton, in Chaleur Bay, and some bays in southern Newfoundland. When female size and published size-fecundity curves were integrated to estimate egg production, larval production (mean number of eggs per trap) appears highest around Grand Manan in the Bay of Fundy, due to abundant large females, and off eastern Cape Breton due to the extremely high catches of berried females. These results are compared to data from the 2012 fishing season. These first two years of sampling have been hugely successful thanks to the unprecedented tri-partite collaboration.

### **Estimates of potential large-scale spatial connectivity of American lobster from a new larval drift model covering most of the species' range.**

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Lobster larvae are planktonic and drift with ocean currents for days to weeks before settling. They may end up settling in areas far away from where they originate, meaning that different areas may depend on one another for their supply of lobster larvae, and thus potential fisheries recruits. This potential spatial connectivity of lobsters by larval drift has been investigated using bio-physical individual-based models coupled to hydrodynamic models of the Gulf of Maine and the southern Gulf of St. Lawrence. We used a new modeling system, incorporating the Atlantic Shelf of North America from Cape Cod, Massachusetts to the Strait of Belle Isle, Newfoundland, to investigate potential spatial connectivity of lobsters at a spatial scale larger than attempted previously. Sensitivity of model predictions to different temperature-

mediated larval development functions (which influence the time and distance larvae drifted before settling) and mortality of larvae was also tested. Our model predicted much connectivity within the Gulf of Maine and Gulf of St. Lawrence, and between these and the Scotian Shelf. Development functions affected the amount of connectivity within and between areas. Mortality did not affect linkages between areas, though it did influence actual numbers of settling larvae. Our model results show that areas separated by long distances could potentially be connected, and also that larval development greatly affects predictions made by models. This model will support further investigations of lobster spatial connectivity and metapopulation dynamics.

## Concurrent Session III: Metapopulation Dynamics & Connectivity

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### Assessing spatial patterns and patchiness of American lobster (*Homarus americanus*) settlement in the Bay of Fundy.

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The objective of this study was to quantify the abundance and spatial pattern of lobster settlement in select coastal habitats of the Bay of Fundy. A spatially nested design comprising 23 sites (300-3,000 m<sup>2</sup>) with appropriate cobble bottom for lobster settlement was used; two to three sites were nested within 11 areas (0.3-20 km<sup>2</sup>), which were nested within one of two geographical regions, Fundy (924 km<sup>2</sup>, six areas) and SW Nova Scotia (3,000 km, n areas). To estimate settlement, we deployed around 400 standardized settlement collectors (15-25 per site) in July of 2009, 2010, and 2011 and retrieved these the following October. In order to assess patchiness, we calculated variance in the number of settlers (or juveniles) at different spatial scales, and then compared these

values to a theoretical distribution obtained by Monte-Carlo simulation and assuming random settlement across sampling units. In both 2009 and 2010, good settlement ( $\geq 1$  settlers/m<sup>2</sup>) was observed in 4/11 areas, medium settlement (~0.5 settlers/m<sup>2</sup>) in 1/11 areas, and low settlement ( $\leq 0.2$  settlers/m<sup>2</sup>) in the remaining 6 areas, with settlement being greater at sites in the Fundy than the Nova Scotia region. Settlement was gregarious, or patchy, when contrasted across sampling units separated by 4-80 km, but not at both lower and higher spatial scales. This study has identified important nursery grounds for lobster in the Bay of Fundy, and suggests some inter-annual consistency in spatial variability in settlement.

### On the activity levels and movements of juvenile American lobsters (*Homarus americanus*) in a nursery area: an ultrasonic telemetry study.

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Our understanding of natural movement and activity patterns of juvenile American lobster (*Homarus americanus*) is limited, being based on laboratory studies and temporally-constrained diving observations. There currently exists no quantitative information on the frequency or magnitude of their activity levels or movements in nature. This study utilized an ultrasonic tracking system (Vemco's VRAP) to provide estimates of activity levels, activity rhythms, and movements of 10 juvenile lobsters within an area of approximately 5,000 m<sup>2</sup>. The lobsters ranged in size from 20 to 47 mm in carapace length, and were probably one to three years old. The study ran in August 2010 in Birch Cove, New Brunswick, Canada, on a shallow lobster nursery area. A

comparison of activity levels between day/night and high tide/low tide periods was completed using a G-test of goodness of fit, and rhythmicity in activity was investigated using periodogram analysis. Most lobsters were nocturnally active and showed a significant period of activity of 24 hours. Tidal height affected the activity levels of some lobsters, but was secondary to the influence of time of day. The LoCoH method was used to calculate daily and study length home ranges for each lobster. The average daily home range (90% utilization distribution) ranged from 27 to 112 m<sup>2</sup> per day for the 10 lobsters. The expanded results of each of the analyses, as well as how they relate to an increase in lobster size, are presented.

## **Concurrent Session III: Metapopulation Dynamics & Connectivity**

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### **Direct determination of age in crabs, shrimps, and lobsters.**

Raouf Kilada,<sup>1</sup> Bernard Sainte-Marie,<sup>2</sup> Rémy Rochette,<sup>1</sup> Neill Davis,<sup>1</sup> C. Vanier,<sup>2</sup> and S. Campana<sup>3</sup>

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The detection and measurement of annual growth bands preserved in calcified structures underlies the assessment and management of exploited fish populations around the world. However, the estimation of growth, mortality, and other age-structured processes in crustaceans has been severely limited by the apparent absence of permanent growth structures. Here, we report the detection of growth bands in calcified regions of two body structures in four decapod species: American lobster (*Homarus americanus*), snow crab (*Chionoecetes opilio*), sculptured shrimp (*Sclerocrangon boreas*) and northern shrimp (*Pandalus borealis*). The technique is thus providing a direct method of age determination. Comparison of growth band counts with reliable, indepen-

dent measures of age indicates that the bands form annually and provide an accurate indicator of age in all of the species examined. Chemically-labeled growth bands were retained through successive molts, as was one of the two body structures containing the growth bands. Growth band formation was not associated with molting or previously-documented lamellae in the endocuticle. Sex-specific growth curves were readily developed from growth band examination in multiple species, suggesting that routine measurement of growth and mortality in decapod crustaceans should now be possible. The implications of this method for future stock assessments and biological studies of crustaceans around the world are likely to be substantial.

### **Further test of a new and direct technique to age crustaceans: length-at-age relationships for American lobster from different thermal regimes.**

Neill Davis, Raouf Kilada, and Rémy Rochette

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Until recently a method to directly age crustaceans did not exist, limiting our ability to model individual growth and population dynamics. A recent study involving four species of crustaceans, including the American lobster (*Homarus americanus*), provided strong evidence that growth band counts found in the eyestalk and mesocardiac ossicle of the gastric mill demonstrate age. The present work looked to further test this new aging technique in *H. americanus*, utilizing the known effect temperature has on growth rates, where lobsters experiencing warmer temperatures should reach a given size at a younger age. Lobsters ranging in size from

15-155 mm carapace length, encompassing young-of-year individuals to the larger individuals caught by the fishery, were collected from several sites between Rhode Island and Newfoundland, near the southernmost and northernmost range of the species, respectively. Initial results of similarly-sized individuals from varying thermal regimes show more bands in colder-water versus warmer-water individuals, as expected if bands are indicators of age. Also presented are the first sex-specific length-at-age relationships, developed using the direct age determination technique, across various latitudes/thermal regimes for *H. americanus*.

## Concurrent Session IV: Human-Natural Systems & Ecosystem-Based Management

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### Contrasting effects of size-selective fishing on Atlantic cod and American lobster: a refuge is critical.

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The potential for size-selective fishing to negatively affect the population demographics of fishes and invertebrates has been recognized for over a century, yet this phenomenon has received remarkably little empirical study. Two case studies from the southern Gulf of St. Lawrence, Canada, are presented and the effects contrasted: 1. Changes in fishing technology and increased fishing efficiency since the early 1980s had the effect of removing the size refuge and imposing unsustainable harvest rates for Atlantic cod (*Gadus morhua*). The fishery removed fast-growing individuals of each cohort at a much faster rate than slow-growth individuals for more than seven years. Over four to five generations of very high exploitation, this resulted in a genetically-dwarfed population in much the same manner as selective breeding

was used to create toy poodles from early domesticated dogs. This dwarfing is contributing to the likelihood that southern Gulf cod will become extirpated in the near future. 2. American lobsters (*Homarus americanus*) are subject to high exploitation (approximately 70% per year) but there is the rigidly enforced minimum size limit, trap design limiting the access of large animals, protection of egg-bearing females, and an upper size limit. This slot fishery allows the lobster to grow through the fishing window after only three or four molts. The surviving lobster may then live to reproduce for 30 to 40 additional years. Thus, large fecund individuals continue to be important contributors to lobster larval production unlike cod, where medium to large individuals were effectively eliminated several (fish) generations ago.

### Long-term sustainability of the American lobster fishery: body size matters.

Diane F. Cowan

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Lobsters of large body size are critical to the long-term sustainability of the American lobster fishery because they have proven survival skills, high reproductive output, and a propensity for large-scale movements. Historically, lobsters reached sizes exceeding 300 mm carapace length, while today a vast majority of lobsters measure <100 mm carapace length. Surviving to a carapace length exceeding 100 mm indicates a lobster has lived for more than a decade, escaped predation, shown resistance to disease, and weathered various climatological conditions. Large lobsters have a relatively high reproductive output because they produce larger gametes (both eggs and spermatophore) and carry larger embryos that grow into larger larvae. Furthermore,

large lobsters are better capable of protecting their broods. In addition to being proven survivors with high reproductive potential, big lobsters have a greater propensity for large-scale movements that deem them (1) more likely to be in the “right place” to avoid adverse conditions including waters that are unfavorably warm; (2) better able to re-seed areas where lobster stocks have been depleted; and (3) more suited to maintaining a strong gene pool in the lobster population. Thirty years of research and personal observations as well as a plethora of scientific literature and fisheries reports attest to the importance of large lobsters in the population and their role in the long-term sustainability of the lobster fishery.

## **Concurrent Session IV: Human-Natural Systems & Ecosystem-Based Management**

### **Roles of legal sizes in the management of American lobster (*Homarus americanus*).**

Yong Chen,<sup>1</sup> Jui-Han Chang,<sup>1</sup> Yuying Zhang,<sup>1,2</sup> Carl Wilson,<sup>3</sup> and Kathleen Reardon<sup>3</sup>

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Minimum and maximum legal sizes are commonly used in the management of many crustacean fisheries for conservation of reproductive potentials. Size limit regulations have been used in the management of American lobster (*Homarus americanus*) in the Gulf of Maine since 1874, when a minimum legal size was introduced in the Maine lobster fishery. Maximum legal size has been implemented in Maine since 1933. The current minimum and maximum legal sizes in Maine are 83 mm and 127 mm carapace length, respectively. Although the legal size is well known in conserving lobster spawning biomass, its impacts on lobster stock dynamics have not been quantified. In this study, using an individ-

ual-based lobster population simulator we developed and parameterized with the Gulf of Maine lobster stock, we evaluate impacts of minimum and maximum legal sizes on the population dynamics of lobster in the Gulf of Maine. Different minimum and maximum legal sizes are used in the study to evaluate the effectiveness of current minimum and maximum legal sizes in conserving reproductive potentials. Different recruitment dynamics and fishing intensity levels are considered in the evaluation and their influence on the effectiveness of the legal sizes is identified. This study will improve our understanding of the role of the legal sizes in the management of American lobster in the Gulf of Maine.

### **The impact of ovigerous lobster movements on egg development, larval hatch, and settlement.**

Jason S. Goldstein and Winsor H. Watson III

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The American lobster (*Homarus americanus*) fishery is one of the most economically important fisheries in the Northwest Atlantic and Gulf of Maine and its success has been attributed, in part, to a high degree of broodstock conservation. Studies of ovigerous lobster movements indicate that some, if not most, display seasonal inshore-to-offshore patterns, and it is generally accepted that these movements serve to expose eggs to warmer water temperatures offshore, which should accelerate egg development. The overall goals of this study were to first confirm that lobsters in coastal waters carried out seasonal inshore-offshore movements and, secondly, to determine the impact of these movements on egg development, hatch, and subsequent settlement. Ultrasonic tracking of both ovigerous (n = 24) and non-ovigerous lobsters (n = 26) revealed that most lobsters move offshore in the late fall

and ovigerous lobsters tend to remain there until after their eggs hatch. Both laboratory and field studies demonstrated that the eggs carried by lobsters that moved offshore actually hatched more than two weeks later than eggs exposed to inshore temperatures. Finally, experimental ocean drifters were deployed in the vicinity of lobsters when their eggs were hatching to determine where these larvae might drift and settle. Most drifters released in offshore hatching locations were carried south and were either near the coast of Massachusetts or offshore bank locations at the time when larvae would settle. Our results suggest that offshore movements of ovigerous lobsters impact when and where eggs will hatch and, subsequently, where new recruits settle. Thus, these data have significant implications for population connectivity and management of this important fishery.

## Concurrent Session IV: Human-Natural Systems & Ecosystem-Based Management

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### Lobster as a source of vulnerability and resilience in Maine fishing communities.

Anna Henry and Teresa R. Johnson

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Maine fishing communities are suffering from a loss of access to fisheries and infrastructure, regulatory impacts, and changes in resource abundance. Many fishers have responded to these changes by intensifying their harvesting of American lobster. Through ethnographic research and oral histories with fishermen, we examine how this increasing dependence

on a single species is affecting the vulnerability and resilience of fishing communities in Maine. Drawing on lessons learned from the lobster fishery, we identify recommendations for improving the resilience of fishers and the communities in which they live.

### A historical and regional perspective of fish predation on lobsters in the Gulf of Maine.

Jonathan H. Grabowski,<sup>1</sup> Graham D. Sherwood,<sup>2</sup> Curt Brown,<sup>2</sup> Robert Steneck,<sup>3</sup> Richard A. Wahle,<sup>3</sup> and Jon Witman<sup>4</sup>

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The extirpation of top consumers has largely altered ecological communities and ecosystem functioning globally. As recently as 25 years ago, scientists documented that predation on large lobsters and other large invertebrates was much higher on offshore ledges in the Gulf of Maine than in coastal waters where overfishing had greatly diminished predator populations. We revisited these sites and quantified predator communities and predation rates to evaluate whether this regional dichotomy still exists. Since many of the offshore sites were closed to fishing in the late 1990s or 2000s, we were also

able to evaluate whether these closures are protecting and rebuilding predator populations. Specifically, we compared predator communities and lobster survival at inshore sites to those in open and closed offshore sites. We found predator communities are still more abundant offshore, but substantial changes have occurred in community structure. These effects were exacerbated at offshore open sites. Our results suggest that continued removal of top predators will result in the release of lobster and other intermediate prey populations.

## abstracts

### Concurrent Session IV: Metapopulation Dynamics & Connectivity

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#### Population structure and the application of reference points to lobster stocks off the Atlantic coast of Nova Scotia and the Gulf of Maine region.

John M. Tremblay and Douglas S. Pezzack

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Off the Atlantic coast of Nova Scotia and in the Canadian Gulf of Maine region there are 14 Lobster Fishing Areas (LFAs). Management of lobster fisheries in Canada is at the level of the LFAs and regulations differ among them by varying degrees. All Canadian fisheries are required to develop reference points and ultimately harvest control rules. Applying meaningful reference points to lobster in this region is a work in progress. One of the issues is the spatial scale at which assessments are done and the reference points applied.

A review of available data on population structure identified groups of LFAs with similar landings trends using cluster analysis. The application of reference points to units larger than LFAs is complicated by the fact that most data are fishery-dependent and unique to LFAs. Alternative approaches are possible from fishery-independent data that originate from records of the lobster catch in surveys directed at other species.

#### Evaluate spatial scales for the assessment of American lobster (*Homarus americanus*) stock in the Maine inshore waters.

Jui-Han Chang and Yong Chen

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Inclusion of data that provide contradicting information about dynamics of target fish populations usually increases uncertainties in stock assessment. For the American lobster, the Gulf of Maine is considered as a single stock unit in the assessment. However, temporal trends in landings differ greatly in different areas within the Gulf of Maine. For example, while landings from Maine tripled between 1981 and 2003 and have since remained high, landings from Massachusetts declined dramatically since 2001. The stock assessment conducted by the Atlantic States Marine Fisheries Commission in 2009 showed that abundance estimates off the Massachusetts coast in the Gulf of Maine were dis-

tinctly different from the Gulf of Maine stock as a whole. This suggests large spatial variability in the dynamics of lobster stock within the Gulf of Maine and current stock assessment scale for American lobster may be too large. It is important to define an appropriate spatial scale of stock assessment that ideally minimizes the contradiction of data information within a stock unit. Using lobster spatial distribution estimated from a habitat model for Maine inshore waters where 80% of the lobster landings occurred, we analyzed and compared population trends at different spatial scales, with implications for the definition of stock assessment scale for American lobster.

## Concurrent Session IV: Metapopulation Dynamics & Connectivity

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### An exploratory analysis of color polymorphism in larval American lobster (*Homarus americanus*): patterns and implications.

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American lobster (*Homarus americanus*) is generally considered monomorphic in color, with a characteristic reddish-brown color pattern. Previous work on juvenile lobsters illustrated short-term color change in response to environmental cues and suggested possible ecological implications of this plasticity. Greater variation in color of larval lobster, relative to later life history stages, has yet to be explicitly addressed. Here we present exploratory analysis of phenotypic plasticity in larval American lobster coloration. We held berried female lobsters collected from four coastal Newfoundland locations at the Ocean Sciences Centre until eclosion, and then obtained digital photographs of newly hatched larvae to score coloration. Through the use of custom image analysis scripts written in Matlab, we automated

the processing and analysis of each image, thus greatly improving processing efficiency and enabling the extraction of detailed color summaries. We explored several possible influences on color frequency distribution including maternal origin, natal region, spawning year, morphology (larval-adult), and predation. Experiments on predation success suggest higher survival of larvae characterized by reddish hues than those with more blue-green color pallets. Analyses also show differences in color morph frequencies among natal regions and maternal origin. These results provide an initial quantitative look at coloration and provide a platform for further analysis to evaluate the role of environment and color plasticity in survival of larval American lobster.

### Identifying local morphometric patterns in the American lobster (*Homarus americanus*) using photograph-based measurements and neural networks.

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Lobsters from different sites show genetic, morphological, and behavioral differences. Differences in body shape may result from genetic and/or environmental factors. To understand what drives patchiness in a population with the potential for high gene flow it is important to distinguish between the two. Using a discriminant function analysis with a series of 65 measurements taken by hand (i.e., with calipers), we showed differences in body shape between lobsters caught at sites separated by as few as 30 km. This method has great discrimination power but can be subject to observer bias. Additionally, the measurement process is time-consuming making it difficult for application in the field. To avoid these problems, we have been developing a promising photo-

tographic method of measuring lobsters that can successfully replicate a number of hand measurements. The photographic method utilizes landmark-based geometric techniques to examine differences in shape between individuals and sites/populations. We will present results obtained with the photographic method including our use of neural networks to identify environmental correlates with differences in shape. Combined with genetic analysis, such correlates may allow us to identify candidate factors for local morphological adaptation of lobster populations. These results will be added to a larger population model that includes genetic, morphometric, behavioral, and environmental variables.

## Concurrent Session IV: Metapopulation Dynamics & Connectivity

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### Population patchiness reflects a balance of the forces of dispersal and aggregation.

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Dispersive forces throughout the life history of the lobster (*Homarus americanus*) have led to predictions of a relatively homogenous population. Larval dispersal, long distance migration, and regular seasonal inshore-offshore migrations suggest that lobster populations should be homogenous over distances of hundreds of kilometers. Yet, lobstermen see local differences in appearance at a 30 km scale. When we applied rigorous morphometric and discriminant function analysis to first-legal-size samples of inshore and offshore lobsters, we found all 22 sites to be different with misclassification rates of 0-60% (mean 35%), somewhat lower in males than in females. Genetic analysis of the same lobsters using microsatellites frequently showed significant differences between sites: 36% of all pairwise male populations and 28% of all female populations were significantly different. Differences larger than 10% were

found only in males. Both morphometry and genetics indicated that males were more resident than females. This may be related to female mate choice. In the third component of our study we tested female preference for local versus foreign males from a site 30 km away. They either did not show preference, or they preferred the company of local males. The latter occurred mostly when the populations were genetically different. Structure varied between regions: Rhode Island and New Hampshire showed greater site differences than Maine and the offshore sites. There was no evidence for connectivity between specific inshore and offshore sites. We suggest that dispersal is to some degree balanced by local aggregation. Initial patchy settlement followed by local adaptation and learned odor preferences could lead to the observed population structure.

### Closing the circle: southern New England's lobster collapse reveals strong environmental signature in the spawner-to-recruit linkage.

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Characterizing the spawner-to-recruit relationship in American lobster stocks has been elusive. Over the past two decades in southern New England, shell disease and stressfully warm summers have caused high rates of lobster mortality and fishery collapse. In a recent time series analysis we revealed the joint effects of variable larval settlement and subsequent shell disease prevalence on the declines in Rhode Island's lobster fishery recruitment. Here we attempt to close the life cycle by evaluating the link between spawners and their offspring as settlers. We expected the region's precipitous declines in lobster brood stock to provide sufficient contrast in the 23-year time series to enable us to detect the long-sought spawner-to-settler relationship. In separate preliminary linear regression analyses, we found a marginally significant spawner-to-set-

tler relationship, but an even stronger correlation with the winter North Atlantic Oscillation (NAO), a proxy for ocean-atmospheric conditions that could influence egg hatching or larval transport and survival in the region. Application of a Ricker spawner-recruit model that includes the NAO Index suggests that the recent series of negative NAO Index years exacerbated the already adverse effects of a depleted broodstock to bring about more diminished settlement than would be expected from the decline in broodstock alone. To our knowledge, this is the first time the spawner-settler-environment relationship has been quantified for a clawed lobster of any species. Together our two analyses underscore the need for a better understanding of both pre- and post-settlement mechanisms that influence cohort success.

## Posters | Anthropogenic & Environmental Stressors

### American lobster in Norwegian waters: a threat to the European lobster?

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Importation of live American lobster (*Homarus americanus*) to Europe has increased considerably the last few decades. Such transport may serve as a vector of invasive species if these animals are somehow released into the wild. Since 2000, 25 American lobsters captured in coastal waters off Norway have been positively identified from DNA-analysis, of which six females were ovigerous. All American lobsters have routinely been checked for the bacteria that cause gaffkemia, all have tested negative so far. In 2009, several American lobsters infected with what has been described as shell disease were captured for the first time. Experiments are, however, needed to verify if this disease is transferable to

European lobster. Also in 2009, DNA-analysis showed that an ovigerous American female captured off southeastern Norway had mated with a local European male, i.e., hybridization had taken place. The hybrids were successfully hatched at Institute of Marine Research in Bergen, and are monitored to assess if the offspring are able to reproduce. Behavioral studies have commenced focusing on competition between hybrid juveniles and pure European juveniles. The presence of live American lobster in Norwegian waters has raised strong apprehension about possibilities for disease transfer, cross-breeding, and ecological interactions (e.g., displacement or “take over”) with the local European lobster.

### Evidence for temperature-mediated settlement in lobster larvae (*Homarus americanus*).

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We examined the potential for low bottom temperatures to inhibit settlement of planktonic lobster postlarvae to the benthos. Field sites were located in Machias Bay, Maine, with one site located within the bay (approx. 11-13 °C) and the second located in the mouth of the bay and exposed to the cold Eastern Maine Coastal Current (approx. 10.5-11.5 °C). We found significantly higher settlement at the warmer site and settlement was below the threshold of detection at the cold water site. Larval supply to these sites was not significantly different indicating a disconnect between larval supply and settlement. In our laboratory trials, postlarvae held at 11 °C exhibited higher mortality, slower development,

and reduced size increase at molt relative to postlarvae held at 13 °C. Our results suggest that very small differences in water temperature may have dramatic effects on settlement patterns on the scale of kilometers due to negative effects of cold temperatures on development and survival. We hypothesize that a temperature threshold may occur at approximately 12 °C, below which settlement of lobster postlarvae is inhibited. Our continuing research will examine this pattern on a regional scale and explore additional factors such as differences in wave energy and food supply that may contribute to settlement patterns.

## **Posters | Anthropogenic & Environmental Stressors**

### **Temperature matters: moving toward a degree-day model for the growth of the American lobster.**

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Thermal variability adds complexity to modeling growth in crustaceans. For the American lobster, whose geographic range spans the steepest latitudinal gradient in sea-surface temperature on Earth, a growth model incorporating temperature effects would be especially valuable to modeling population dynamics. Here we present a probabilistic step-wise growth model for the three thermally distinct regions: Bay of Fundy, coastal Gulf of Maine, and southern New England shelf. This model merges estimates of size-at-age of young lobsters with molt process information for older

lobsters. Temperature is incorporated by determining the probability of molting as a function of growing degree-days. We found that “correcting for” thermal effects by the degree-day method does not entirely explain regional differences in growth, suggesting other environmental factors may be at work. Understanding the influence of temperature and other factors on growth would provide more biological realism and generality to population dynamics models, and will be especially relevant in the context of a changing climate.

### **Lobster (*Homarus americanus*), a new host for marine horsehair worms (*Nectonema agile*, Nematomorpha).**

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*Nectonema* species are parasites of decapod crustaceans and the only known representatives of the otherwise freshwater/terrestrial taxon Nematomorpha. *Nectonema agile* is one of five marine species within the taxon Nematomorpha, commonly known as horsehair worms. We report the American lobster (*Homarus americanus*) as a new host for *N. agile*, a first record among astacidean decapods. A female, approxi-

mately 590 mm long, was found in the body cavity of one female lobster specimen during a size-at-maturity study of this species. We assume lobster to be a very rare host for *Nectonema*. We are interested in conducting further research in the Bay of Fundy to determine infestation rates of marine decapods by this parasite.

### **Seasonal and sexual variation in the thermal preferences of estuarine lobsters.**

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Environmental variables such as temperature influence lobster distribution based not only on thermal tolerances but also on behavioral responses within their thermal niche. We have determined the thermal preferences of adult lobsters (*Homarus americanus*) in the laboratory and then compared these data to seasonal lobster movements and distributions in the Great Bay Estuary, New Hampshire. In the laboratory, lobsters preferred water temperature of  $11.0 \pm 0.6$  °C, or  $2.8 \pm 0.7$  °C warmer than mean ambient temperature during the colder months of the year. However, during the warmer months they selected  $15.7 \pm 0.4$  °C, which was only  $0.2 \pm 0.4$  °C warmer than the ambient temperature. During the colder months, but not the warmer months, male lobsters selected warmer temperatures than females. Overall, lobsters had a final preferred temperature of 15.9 °C. Catch per unit effort data from the estuary were

highest at sites where temperatures were similar to the laboratory-determined preferred temperatures and lowest at sites where temperatures were  $\geq 18$  °C or  $< 12$  °C. Significantly more males than females were captured per trap haul at temperatures  $> 16$  °C. Furthermore, lobsters ( $n = 484$ ) tagged and subsequently recaptured within seven to 35 days moved relatively little when temperatures were similar to the preferred temperatures. This combination of laboratory and field data suggests that thermal preferences influence the distribution and movement of lobsters in thermally heterogeneous habitats such as estuaries. Furthermore, our results suggest that the skewed lobster sex ratios regularly observed in estuaries may result from the differential movements of males and females with potential implications for changes in distribution and performance (e.g., reproduction) due to climate change.

## Posters | Anthropogenic & Environmental Stressors

### Effect of ocean acidification on American lobster.

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Ocean acidification resulting from the global increase in atmospheric CO<sub>2</sub> concentration is emerging as a threat to ecologically and economically important marine species, including American lobster (*Homarus americanus*). Based on ocean pH levels predicted for 2100, we studied the effects of reduced seawater pH on the growth (carapace length) and development (time to molt) of American lobster larvae throughout stages I-IV. Larvae were reared from stage I in either acidified (pH = 7.7) or control (pH = 8.1) seawater. Organisms in acidified seawater exhibited a significantly shorter carapace length than those in control seawater at each stage. Larvae in acidified seawater also took significantly more time to reach each molt than control larvae. In

nature, slowed progress through larval molts could result in greater time in the water column, where larvae are vulnerable to pelagic predators, potentially leading to reduced benthic recruitment. We also found evidence of reduced survival when reaching the last stage under acidified conditions. Thus, from the perspective of larval ecology, it is possible that future ocean acidification may harm this important marine resource. Further testing into multistressor effects of ocean acidification and warming on larval growth, development, metabolic scope, survival, and shell mineralogy are planned in a new acidification lab for the lobster hatching season in 2013.

### Comparison of shell disease prevalence in southern Massachusetts from fishery-independent and fishery-dependent data sources.

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Massachusetts Division of Marine Fisheries has two data sources for monitoring shell disease in American lobsters (*Homarus americanus*). The first survey is conducted as part of a fishery-dependent monitoring program, where the biologist examines a sub-sample of lobsters from commercial trap sampling. For the second survey, the biologist examines all lobsters caught in a fishery-independent ventless trap survey. During both surveys, sampled lobsters are assigned a shell disease code based on visual examination of the lobster's body, including carapace, claws, legs, and abdomen. The code is based on the percent of the body that is covered with disease symptoms: 0%, 1-10%, 11-50%, or >50% (none, light, moderate, or severe, respectively). Other data collected include carapace length, sex, ovigerous status of females, and catch location. Data from the commercial trap monitoring

program consistently show a higher proportion of lobsters afflicted with shell disease than the fishery-independent survey suggests. Both surveys show similar temporal trends in disease prevalence, and indicate that larger lobsters, particularly ovigerous females, are most likely to have disease. Interpretation of the data from the ventless trap survey suggests that location and depth affect lobster demographics, and thus observed spatial patterns of disease. The ventless trap survey, as a fishery-independent survey, provides a more accurate indication of the overall disease rate in the lobster population. While historically limited to state waters in southern Massachusetts, a recent expansion of the ventless trap survey into federal waters will augment our ability to monitor the population-level incidence of shell disease.

## **Posters | Anthropogenic & Environmental Stressors**

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### **Tolerance of juvenile lobster (*Homarus gammarus*) to the anti-parasitic drug teflubenzuron.**

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To reduce infestation of salmon lice (*Lepeophtheirus salmonis*, Krøyer) in Atlantic salmon it is necessary to use anti-parasitic drugs, administered orally via feed or as bath treatment. Flubenzurons are orally administered drugs that act by interfering with the chitin synthesis in salmon lice. Since the bioavailability of flubenzurons in salmon are moderate and the metabolism low, most of the drugs will be released from the fish as parent compound via feces, with concentrations twice the initial concentration. Flubenzurons are less soluble in water and associate readily with organic particles, and once reaching the sediment the compounds do not readily disappear. Teflubenzuron and diflubenzuron were frequently in use in Norway in the late 1990s. From 2002, emamectin, cypermethrin, and deltamethrin were most commonly used but due to

instances with reduced sensitivity, flubenzurons were reintroduced in 2008. Flubenzurons are rather non-toxic to most marine species but potentially highly toxic to species undergoing molting, like lobster, crab, and shrimp. The amount of published data on the effect of flubenzurons on non-target species is limited. On this basis, a study was designed to examine the effect of teflubenzuron on juvenile lobster (*Homarus gammarus*) when offered doses of 10 and 20 mg/kg daily for seven days, mimicking consumption of excess pellets and fecal particles. The concentration after eight days was on average 2,026 ng/g, but was reduced significantly after 20 days. Mean value of first survivors was 152 ng/g. Total mortality was 37%, independently on dosage; 22% of the surviving juveniles had developed senescent damages.

## Posters | Food Web Dynamics

### The effect of sedimentation on the settlement behavior of the American lobster (*Homarus americanus*).

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Most benthic marine invertebrates have a complex life cycle involving a pelagic dispersal phase followed by a benthic settlement phase. The transition between these phases is known as larval deposition and is critical to the American lobster (*Homarus americanus*). Larval deposition on the sea bottom is observed at stage IV. Lobster larvae are then vulnerable to various predators and will adopt a cryptic behavior to increase survival. Of the various biotic and abiotic factors that may affect larval deposition, substratum modifications due to sedimentation are being investigated. Climate change and diverse human activities can affect sedimentary regimes in

ways that ultimately impede recruitment in American lobsters. The main objective of this study is to quantify how different thicknesses of fine sediments over preferred substrate will affect the larval behaviors involved at settlement. These behaviors may vary not only over a given season but also within a few days following the molt to stage IV. Larvae used in this study were produced in an experimental hatchery from June to August 2012 and experiments were conducted on stage IV larvae at day two, three, and four after molting. Behavioural observations including time budgets are presented.

### Physiological responses to feeding and digestion in lobsters.

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The typical size meal consumed by lobsters was 2-4% of their body weight, and this varied somewhat with the size of the individual. The ingestion and subsequent assimilation of a meal is associated with a general increase in metabolism (measured as an increase in oxygen uptake) termed the specific dynamic action of food (SDA). When lobsters consumed a meal totalling 0.5%, 1.5%, or 3% of their body weight there was a subsequent increase in scope (peak oxygen consumption), the time to reach peak oxygen consumption, the duration of elevated oxygen uptake, and total energy expended. These characteristics increased with increasing meal size. The size of an individual had a lesser effect

on characteristics of the SDA. Larger lobsters took a longer time to reach peak oxygen uptake and had a greater overall SDA compared with smaller lobsters. The passage of a radio-opaque meal was followed through the gastric system. There was no effect of meal size on the time required to clear each region of the gut system. Lobsters emptied the foregut within 115 h-130 h and the entire gut system was cleared after 150 h. These evacuation times were considerably longer compared with brachyuran crabs. The physiological consequences of digestion and assimilation are discussed and compared with those of other decapod crustaceans.

### Seasonal and centuriel change in smooth dogfish (*Mustelus canis*) diet in Buzzards Bay, Massachusetts.

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The smooth dogfish (*Mustelus canis*) is broadly distributed along the east coast of the U.S., but little is known of its feeding ecology in the northern portion of its range. To characterize and quantify the diet of this species, stomach samples were collected during a random stratified longline survey and a standardized bottom trawl survey in Buzzards Bay, Massachusetts. A non-lethal stomach eversion technique was used to extract stomach contents, which consisted mostly of crustaceans, accounting for 71% of the diet by percent Geometric Index of Importance (% GII) in the spring, 90% GII in the summer, and 87% GII in the fall. *Cancer irroratus* was the most important prey species in the spring (30% GII) and summer (31% GII), while *Homa-*

*rus americanus* was the most important prey species in the fall (21% GII). More than half of *H. americanus* found in the diet consisted only of claws and legs, which can be regenerated. It is possible that many of the *H. americanus* found in the diet avoided predation by autotomizing an appendage and therefore survived. Based on Bray-Curtis similarity coefficients and non-metric multidimensional scaling analysis, *M. canis* diet did not significantly differ by sex, size, or season. In comparison to diet data collected in the same area more than 100 years earlier, we found significantly more *Squilla empusa*, *Thalassinidea* spp., *Cancer borealis*, and *Panopeidae* spp., and significantly fewer *Brevoortia tyrannus*, *Ovalipes ocellatus*, and *Ensis directus*.

## **Posters | Human-Natural Systems & Ecosystem-Based Management**

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### **Evaluation of fixed-station sampling for lobster settlement survey in the Gulf of Maine.**

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Settlement surveys have been conducted for monitoring the early life history of lobster and providing time series abundance indices of newly settled lobster in the Gulf of Maine. Information on the spatial and temporal dynamics of settler abundance is critical for assessing the lobster population and its response to environmental changes. However, the interpretation and quality of the information are largely determined by the sampling design. For the settlement survey in the Gulf of Maine, the sampling stations are selected in a non-random fashion and not changed from year to year, which contradicts with random survey designs used for most fisheries-independent survey programs. This study is

designed to evaluate the performance of such a sampling design in capturing spatial and temporal dynamics of lobster settlers. Both analytical approach and simulation method are used in the study. For the analytical method, an index of persistence measures how stable spatial distribution is between years. Lobster settlement with low persistence suggests randomization. The “true” populations of lobster settlers are simulated based on the actual survey data using a habitat model and fixed and random designs applied to sample the simulated populations for evaluating the performance of the designs in capturing built-in dynamics of settlers.

### **Considering harvester responses to regulatory changes in management strategy evaluation of the American lobster fishery.**

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Uncertainty stemming from both biological and human systems is a pervasive problem in fisheries management. Recent studies have tended to focus on scientific uncertainty about the status of resources, which is only part of the uncertainty. Uncertainty in responses and actions of fishermen with respect to changes in resources and management has received far less attention and rarely has been considered in the policy-making process. While catch is high in the Maine lobster fishery, the economic status is still in question because of increases in bait and fuel prices and recent declines in ex-vessel prices. According to a Maine Department of Marine resources survey, 76% of fishermen favored an effort reduction with hopes of increasing profits. Effort in the Maine lobster fishery is currently controlled by a per-vessel trap limit and limited

licenses. Reducing the trap limit may be a possible solution to cutting back on effort. However, fishermen may simply respond by minimizing trap soak time and making more trips to compensate for this effort control. Failure to consider potential behavioral changes of harvesters may lead to unintended consequences that do not reflect management goals. We developed a comprehensive model including an economic submodel and individual-based lobster population simulator to evaluate lobster management strategies under different biological and economic conditions and fishermen responses to regulatory changes. The results of this study can simultaneously address possible uncertainties from both the biological and human components of this fishery to aid in management.

### **A comparison of lobster catch from recruitment and commercial traps in the upper Bay of Fundy.**

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The American lobster (*Homarus americanus*) recruitment index from standardized traps project began in 1999 along the Atlantic coast of Nova Scotia (more recently in some areas of the Bay of Fundy) with the objective of providing an index of the number of lobsters that will molt into the legal sizes in future seasons. In more recent years, the funding for at-sea sampling of commercial catches has decreased, and the lobster recruitment index has been suggested for purposes that the program was not originally intended, such as calculating exploitation rate. The data collection from Lobster Fishing Area 35 in the upper Bay of Fundy is unique because at-sea sampling of commercial catch and sampling from standardized recruitment traps have occurred concurrently at moderate to

high levels since fall 2008. This dataset was used to describe the similarities and differences between the two trap sampling methods. The size structure of lobsters caught in the recruitment trap was notably different from the commercial traps. The recruitment traps retained more sublegal lobsters while still capturing the distribution of the legal lobster when compared to the highly right-skewed size frequency of commercials traps. As expected, the catch rate of sublegal lobster is higher in recruitment traps than commercial traps, and the catch rate of legal lobster is higher in commercial traps than recruitment traps. Within season and annual trends in catch rate of the commercial and recruitment traps are compared.

## Posters | Human-Natural Systems & Ecosystem-Based Management

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### A non-invasive method for determining mating success in female American lobsters (*Homarus americanus*).

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Despite being one of the most productive fisheries in the Northwest Atlantic, much remains unknown about the natural reproductive dynamics of American lobster, particularly regarding how exploitation impacts reproductive potential. Recent work in exploited crustacean populations suggests there are circumstances where mature females are unable to achieve their full reproductive potential due to sperm limitation. To examine this possibility in different regions of the American lobster fishery, we developed a reliable and non-invasive method for sampling large numbers of female lobsters at sea. We inserted a blunt-tipped needle into the seminal receptacle of females to both determine the presence or absence of a sperm plug and to detect sperm. In order to

confirm that the method was reliable before applying it under field conditions, we conducted a series of control studies in the laboratory. We sampled a total of 294 female lobsters and dissected those seminal receptacles that yielded negative results to confirm the absence of sperm (assuring against false negatives). A total of 93% of females had a sperm plug, while the remainder did not ( $n = 20$ ). We concluded that most observations of females with sperm plugs but no sperm cells in the sample were the result of the sampler not inserting the needle to a sufficient depth to collect the sperm. Hence, the presence of a sperm plug is a reliable indicator of a female bearing sperm supplies.

### Quantitative value of coastal habitats for exploited species.

Romuald N. Lipcius, and members of ICES Workshop on the Value of Coastal Habitats for Exploited Species

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Although the influence of coastal habitats on survival, growth, and reproduction of exploited marine species has been demonstrated widely, the absolute value of these habitats to their population dynamics has rarely been quantified. Hence, ICES sponsored a Workshop on the Value of Coastal Habitats for Exploited Species in June 2012 at ICES Headquarters in Copenhagen, Denmark. The workshop laid the foundation for determining the production value of coastal habitats (e.g., seagrass beds, kelp beds, rocky bottom), feeding grounds, and spawning areas by documenting case studies where the quantity and quality of coastal habitats are linked to population dynamics of exploited species; synthesizing the evidence for the importance of coastal habitats to exploited species; and establishing quantitative methods for determining how coastal habitats influence population

abundance and fishery yield. The findings indicated: (i) there is limited information on species utilization of some coastal habitats, particularly kelp forests, rocky shores, and macroalgae, though the information suggests that these habitats are essential for many species; (ii) the majority (71%) of commercial species utilize coastal habitats, but for most species there is inadequate information to quantify the value of coastal habitats to population and fishery production; (iii) information is needed both on population fitness in different habitats (habitat quality), and on the availability of different habitat types (habitat quantity), specifically comprehensive habitat maps; and (iv) there are various mathematical modeling approaches that can be used to answer these questions. This presentation portrays the general findings and details with reference to the European lobster *Homarus gammarus*.

## **Posters | Human-Natural Systems & Ecosystem-Based Management**

### **Differential mating success of female lobsters in Buzzards Bay, Massachusetts: spatial segregation of mature versus immature females or an indication of Allee effects?**

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The potential for rebuilding the Southern New England American lobster (*Homarus americanus*) stock partially depends on the reproductive capacity of the population. However, low abundance, coupled with female-skewed sex ratios in some areas, could set the stage for sperm limitation. In two inner and two outer regions of Buzzards Bay, Massachusetts, mating success was determined in female lobsters by examining their seminal receptacles for presence of a spermatophore. Data were compared to existing size-at-maturity indices to determine if all the potentially mature females were actually mating. Results indicated that while many smaller-than-expected females mated, some larger lobsters that should have mated did not. There was a regional component to mating success, wherein larger females that had not mated were primarily found in the inner regions,

which was contrary to expectations based on sex ratio skews. Our results suggest that either lobster density or differential habitat preferences between immature and mature females influenced observed mating success. If mature females leave the inner regions of Buzzards Bay due to stressful water temperatures, the females sampled inside the Bay may have been disproportionately immature, thus explaining spatial differences in spermatophore presence. Alternatively, decreased mating success of larger females in the inner regions may be related to mate-finding Allee effects resulting from low abundance. Future sampling should incorporate maturity assessments to clarify female maturity status. Finally, additional work is needed to determine whether Allee effects are present in the lobster mating system and at what critical density threshold these effects may depress reproductive output.

### **Ecosystem-based management in Norway and Europe: Where are the lobsters?**

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Norway has developed ecosystem-based management plans (EMPs) for the Norwegian jurisdiction areas of the Barents Sea and the Norwegian Sea. A plan is in preparation for the North Sea and the Skagerrak. Simultaneously, the European Union has implemented the Marine Strategic Framework Directive (MSFD) for all E.U. countries. Both concepts include "descriptors" or "indicators" as means to describe the state and trends of ecosystem qualities, and both are limited to the open seas. The coastal waters are managed by the Water Directive (WD), ratified by E.U. and Norway. While the EMP and MSFD consist of selected biological indicators along with water and habitat qualities, the WD is linked mainly to water and habitat qualities. None of the concepts suggest responses for future climatic changes and shifts in ecosystem regimes.

In Norway the management of commercially harvested or protected species is still being managed by traditional regulation and not yet influenced by the EMPS. Unlike the WD/MSFD, Norwegian EMPS have advisory purposes, but no regulatory powers. In Norway, EMPS for coastal waters are not officially discussed. It may be challenging to adapt the open seas EMPS for coastal waters, as it may conflict with the WD and the public society. Management of the commercial and recreational fisheries, like the lobster fishery, is still mainly based on single-species regulations, especially in coastal waters. For lobsters, both the red-listed *Homarus gammarus* and the black-listed *H. americanus*, inclusion in EMPS are not yet within reach.

### **Collaborating with the lobster industry to assess bait availability in inshore Maine waters.**

Katharine V. Wurtzell,<sup>1,2</sup> Graham Sherwood,<sup>1</sup> Adam Baukus,<sup>1</sup> and Curt Brown<sup>1</sup>

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There has been a reduction of more than 50% in the allowable harvest of herring over the past several years without any direct estimates of the herring resource in Area 1A. This has shifted bait supply and demand dynamics and underscores the lobster industry's dependency on and susceptibility to the fate of herring. The Gulf of Maine Research Institute, in collaboration with the Maine Lobstermen's Association, conducted an acoustic survey of near-shore Atlantic herring (*Clupea harengus*) in the fall of 2012. It is a prime example of collaborative research, as fishing vessels will be utilized for all aspects of the survey. Ten lobster boats, equipped with Simrad ES70 echo-

sounders, surveyed pre-determined acoustic transects along the coast each week; additionally, a chartered herring boat collected samples for target strength verification and ecological studies. Standard echo integration techniques were used to estimate numerical and biomass density of herring. Preliminary results will then be expanded to total abundance and biomass to provide direct and quantitative estimates of herring critical for informed management decisions that balance conservation needs for sustaining herring populations and economic needs of the lobster and herring industries.

## Posters | Metapopulation Dynamics & Connectivity

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### Fishermen and Scientists Research Society: from the ground up.

Shaun Allain, Patty King, Tricia Pearo, and Shannon Scott-Tibbetts

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Established in January 1994, the Fishermen and Scientists Research Society (FSRS) is a nonprofit, charitable organization which is an active partnership between fishermen and scientists. The FSRS was developed with the overall objectives to promote effective communication between fishermen, scientists, and the public, and to establish and maintain a network of fishermen and scientists capable of conducting collaborative research and collecting information relevant and necessary to the long-term sustainability of marine fisheries. The FSRS is involved in a number of lobster-related research projects through collaborations with Fisheries and Oceans Canada, various universities, and lobster fishermen across Nova Scotia and New Brunswick. One of the main

projects with which we are involved is a lobster size-at-maturity study. This is a study to determine female lobster size at maturity in various areas of Nova Scotia including Lobster Bay, Tangier, and Port Mouton. The FSRS also is involved in a phase of the Canadian Fisheries Research Network initiative dealing with berried lobster distribution in Atlantic Canada (Lobster Node). Another important project is the Lobster Collector Project. In 2006, a collaborative project between Fisheries and Oceans Canada and the FSRS was implemented to better understand the settlement of young-of-the-year American lobsters in deep and shallow areas at selected regions along the coast of Nova Scotia.

### Survival and growth of post-larval lobsters on different settlement substrates.

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In the laboratory, post-larval lobsters have been observed to swim over, explore, and manipulate different substrates for different amounts of time depending on the substrate's ability to provide shelter. Whether these behavioral choices affect energetic expenditure, growth, and survival is unknown. We are addressing this question in the laboratory by comparing survival, time to molt, growth increment, and lipid profiles of lobsters settling and molting on cobble, mud, sand, or a bare acrylic tank. How long settlers swim before settling influences dispersal by water currents and affects population connectivity. If energy used in substrate manipulation reduces survival and growth, this could limit recruitment upon substrates requiring shelter construction. In the wild, lobster

settlers are typically found in cobble habitat where overlapping stones provide ready-made shelter. In the laboratory, settling lobsters prefer cobble but will also excavate burrows in a mud substrate. We are deploying cobble-filled cages ("collectors") onto muddy seafloor to test for the presence of recently settled lobsters on mud. Settlers in mud may prefer to colonize the cobble in collectors where we can enumerate them. Finding recently settled lobsters in mud would indicate mud also supports new settlers and early juvenile stages with implications for recruitment on this type of substrate, which is abundant in the Bay of Fundy and in many parts of the species' range.

## **Posters | Metapopulation Dynamics & Connectivity**

### **Connectivity and stock structure of American lobster (*Homarus americanus*) in Atlantic Canada.**

Rémy Rochette,<sup>1</sup> Laura Benestan,<sup>2</sup> Louis Bernatchez,<sup>2</sup> Joël Chassé,<sup>3</sup> Michel Comeau,<sup>4</sup> Kristin Dinning,<sup>1</sup> Marthe Larsen Haarr,<sup>1</sup> Peter Lawton,<sup>5</sup> Bryan Morse,<sup>1</sup> Patrick Ouellet,<sup>3</sup> Brady Quinn,<sup>1</sup> Bernard Sainte-Marie,<sup>3</sup> Guðjón Már Sigurðsson,<sup>1</sup> and John M. Tremblay<sup>6</sup>

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4. Fisheries and Oceans Canada, Moncton, NB

5. St. Andrews Biological Station, Fisheries and Oceans Canada, St. Andrews, NB

6. Bedford Institute of Oceanography, Fisheries and Oceans Canada, Dartmouth, NS

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The Lobster Node of the Canada Capture Fisheries Research Network comprises a five-year collaboration between industry, government, and academia aiming to elucidate stock structure and connectivity of the American lobster in Atlantic Canada. It proposes to achieve this by undertaking five integrated research activities: (1) assessing the input of larvae into the system by quantifying the abundance and size of egg-bearing females collected by fishermen at 50-75 km intervals along the coastline, and determining whether all larvae can be "treated equal" by quantifying non-genet-

ic maternal effects and population-level genetic effects; (2) using an individual-based biophysical model to predict the dispersal and settlement of these larvae, and comparing some of these values to the abundance of postlarvae, juveniles, and adults; (3) studying the effect of substrate characteristics on settlement behavior, and investigating the patterns and processes (e.g., larval supply, wind-driven currents) underlying patchiness of settlement at different spatial scales, to further parameterize and validate our dispersal-settlement model; (4) using traditional tagging data and ultrasonic telemetry to quantify the movements of different size/age lobsters from different regions, and develop a conceptual model of the importance of these movements to connectivity among subpopulations; and (5) developing large quantities of small neutral and non-neutral genetic markers to refine our understanding of lobster populations genetics and patterns of local adaptation. This research is expected to inform best management practices, particularly where these depend on the connectivity between lobster management areas. But perhaps more importantly, it is hoped that it will constitute the foundation of a lasting partnership between lobster fishermen, academics, and government scientists.

### **Lobster Recruitment Index from Standard Traps (LRIST)**

Shannon Scott-Tibbetts

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The Lobster Recruitment Index from Standard Traps (LRIST) project began in the spring of 1999. The goal of the project is to provide an index of the number of lobsters that will molt into the legal sizes in the coming seasons. The project was initiated by the Fishermen and Scientists Research Society in cooperation with the Invertebrate Fisheries Division of Fisheries and Oceans Canada at the Bedford Institute of Oceanography. The initial phase of the project was planned for five years but after reviewing the project's usefulness, it is scheduled to continue for the foreseeable future. This project involves over 150 volunteer fishermen from LFAs 27-35 who fish standardized traps and take measurements of the lobster

caught. These measurements are recorded in a logbook using a specially designed gauge with 15 different size increments. Participating fishermen also monitor bottom temperatures with a minilog temperature gauge in one of the standard traps. These bottom water temperatures are forwarded to the oceanographers at the Bedford Institute of Oceanography and are added to their coastal temperature monitoring database. The lobster information gathered has been used by Fisheries and Oceans Canada in their lobster stock assessments, helping them understand the lobster populations around the Scotian Shelf area of Nova Scotia.

## Posters | Metapopulation Dynamics & Connectivity

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### **Effect of habitat characteristics on American lobster (*Homarus americanus*) recruitment.**

Guðjón Már Sigurðsson, Lauren Ellis, Gregory Wittig, and Rémy Rochette  
University of New Brunswick, Saint John, NB

Relatively little is known about the settlement selection processes of the American lobster outside the laboratory. In this field study, done using settlement collectors in southwestern Bay of Fundy, we aimed to estimate whether cobble size had an effect on settlement densities observed and whether scarcity of available substrate for settlement in an area could intensify settlement in suitable habitat in that area (“oasis effect”). Our results show that settlement was higher in

smaller and medium-sized cobbles, while no settlement was observed in large cobbles. No “oasis effect” (intensification of settlement) was noted in settlement collectors surrounded by poor settlement habitat (sand) in comparison to settlement in collectors surrounded by good settlement habitat (cobble). Juvenile densities were higher in the collectors on sand, suggesting oversaturation of juvenile lobsters in nearby cobble habitats.

### **Presence of a light-sensitive molecule, cryptochrome, in the ventral nerve cord of lobsters (*Homarus americanus*).**

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American lobsters express daily rhythms of locomotion that are strongly influenced by endogenous circadian clocks. These clocks, in turn, are synchronized and entrained to natural light:dark cycles using inputs from a variety of photoreceptors. In 1934, Welsh and Prosser discovered extra-ocular, touch- and light-sensitive neurons in the ventral nerve cord of crayfish. More recent studies have provided some evidence that crayfish without eyes can entrain to light:dark cycles. The hypothesis we tested in this study was that the extra-ocular photoreceptors in the ventral nerve cord of lobsters contain the ultraviolet-a/blue-green light-sensitive protein cryptochrome and thus might serve as a means for entraining circadian clocks to a light:dark cycle. Immunohis-

tochemistry was used to stain these neurons with Drosophila anti-cryptochrome polyclonal rabbit IgG primary antibodies and goat anti-rabbit secondary antibodies conjugated to fluorophore Alexa 488. Cryptochrome was found in 30 neurons in the posterior region of the sixth abdominal ganglion. In addition, cryptochrome was observed in two to four neurons in each other abdominal ganglion and in axons extending the length of the ventral nerve cord. Cryptochrome also was found in the sub-esophageal ganglion but not in any of the thoracic ganglia. Interestingly, some cryptochromes respond to magnetic fields and thus might also play a role in lobster orientation and migrations.



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