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CNH: Fine-Scale Dynamics of Human Adaptation in Coupled Natural and Social Systems: An Integrated Computational Approach Applied to Three Fisheries

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Preview of Award 0909449 - Final Project Report

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Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	James A Wilson

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Accomplishments

* What are the major goals of the project?

The major goals of this project were (1) to gain a better understanding of the way the fine scale learning and adaptation of individual fishermen leads to the emergence of private incentives and informal, self-organized, social arrangements, (2) to explore the mechanisms of this emergence by building computational models of individual learning and adaptation and (3) to investigate the policy implications of this kind of fine scale conception of fisheries processes.

Informal institutions (norms, customs and, especially, self-organized social structure) are important because they help us understand the extent to which private interests might reinforce or impair on-going resource management and, consequently, the sustainability of coupled human and natural systems. The broad hypothesis driving the study is that the informal social structure that emerges from competitive interactions among fishermen reflects the way the circumstances of the natural system affect the costs of acquiring useful knowledge. The argument supporting the hypothesis is that useful knowledge can be obtained by autonomous search or by communication with other agents. In regular and random environments, autonomous search and atomistic competition tends to be favored because other agents have little valuable knowledge. In complex but organized environments, communication and cooperation tend to be favored because other agents do have valuable knowledge. Depending upon the circumstances in the fishery these informal arrangements may or may not create a foundation for collective action and, consequently, the possibility of conservation of the resource (Wilson, et al. 2013b)

To explore this hypothesis we developed models that employ an evolutionary computational approach that originated in the field of artificial intelligence; we modified that approach and applied it to a multi-agent system that includes information about the basic biology of three fisheries (lobster, groundfish, and urchin) and, from our own field work, the human participants in those fisheries (Wilson et al. 2013a; Johnson et al. 2013). The models we have designed are not intended for quantitative prediction but for a better qualitative understanding of the multiscale dynamics of adaptive, coupled systems.

As far as we know, the use of evolutionary computation applied to the understanding of complex coupled systems, or for that matter any living, complex multi-agent system, is unique. We adopted this modeling approach because self-organization in living systems is the product of learning and adaptation. Mathematical and agent-based models of biological and social systems require the modeler to specify the range of conditional (adaptive) behavior of agents. But in a complex co-evolving environment the adaptive possibilities open to agents are extensive and not likely to be fully anticipated by the modeler's knowledge of past behavior. The evolutionary learning algorithms we employ are used to create agent-based models in which the behavioral rules of the human agents are not specified by the modeler but are the product of a constrained evolutionary search of a complex environment (Wilson et al. 2013a and described in more detail below). These kinds of models shift the knowledge required of the modeler towards an understanding of the kinds of information and the constraints affecting the agents' decision making process; the evolutionary computation searches out and tests likely adaptive possibilities obviating the need to specify the conditional behavior of agents. The method we adapt from artificial intelligence is called a learning classifier system (LCS); the coupled natural and human environments we explore are three fisheries in which the social context and the search problem posed by the targeted species is very different; the agents in the models are fishermen (Wilson et al. 2013a; Johnson et al. 2013; Wilson et al. 2013b).

[In the summaries below we assume previous annual reports are available to the reader and limit our references to only a few of the summary articles produced in the project.]

* What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

Major Activities: Over the course of the project we:

1. Developed and refined evolutionary computational approaches (LCS in particular) for modeling individual learning and adaptation in coupled systems. This involved two principal modifications to the evolutionary algorithms commonly used in computer science:
1. We introduced a hierarchical LCS structure that reduces the agent's search space by several orders of magnitude; this makes LCS computationally

tractable in a complex environment and allows agent learning and adaptation.

2. We introduced the closely related concepts of information accuracy and opportunity cost. In multi-agent systems this modification of the LCS approach induces economizing behavior and leads to the formation of persistent social structure.

- We developed an interview methodology appropriate to the requirements of evolutionary modeling.
- We applied this conceptual approach to an analysis of three very different fisheries — groundfish, lobster and urchins.

This evolutionary approach led to the following ideas:

1. The self-organization of a living system occurs only when information is costly.

1. In simple or random environments the cost of information is low or zero and the agent's search problem is minimal. In these circumstances there is no value to cooperative behavior and persistent organization.
2. In complex environments costly information induces cooperative, economizing behavior and leads to persistent individual relationships and groups; it is the principal engine of self-organization.

- In the human part of a fisheries system persistent self-organization lays the civil foundation for conservation.
- In the absence of a civil foundation, the self-organizing incentives and the ability to seek a conservation solution are weak (Johnson et al. 2012; Steneck et al. 2010; Wilson et al. 2013).
- In a complex, coupled system, overfishing is best characterized as the erosion of the self-organization, i.e., the ecological structure, of the natural system. In a metapopulation so long as regulation occurs at a scale greater than the scale of the population components the overfishing dynamic is characterized as the piece by piece loss of components.

We summarize these points in the 'boxes' below.

Modeling learning and adaptation

In human systems adaptation results from the acquisition and use of information. The acquisition of information is not trivial and not easy to model. Valuable information, i.e., information that conveys new 'data,' is particularistic and costly to acquire. Its meaning (and value) to the recipient , i.e., the extent of its surprise, is a function of the recipient's prior knowledge and the circumstances of the conveyance. This context dependent meaning causes resource-limited agents to economize in the use of resources for the acquisition of information. Because the possible information an agent might acquire is extremely large, agents focus their search and the kinds of knowledge they acquire and use. That process of focusing, or specialization, is the engine of self-organization, i.e., of informal social and economic structure.

To model the emergence of self-organization we created models of individual learning and adaptation. These models place multiple self-interested agents (fishermen) in a complex environment, which contains a patchy, dynamic and valuable resource. Our models are based on the current understanding of the biophysical and ecological understanding of the Gulf of Maine (Incze et al. 2010; Jordaan et al. 2010; Lorenzen et al. 2010; Steneck and Whale 2013) and on intensive, repeated interviews with fishermen. Agents can search the environment on their own and they can communicate with one another. Agents compete with one another and have limited time to search the environment and acquire the resource. Their actions and those of other agents change the spatial structure and abundance of the resource, creating a dynamic fitness landscape, and, in some conditions, persistent self-organized individual and group relationships.

We use a modified learning classifier system to model agent behavior. An LCS is a powerful search technique that is widely applied in computer sciences and well suited to searching out the adaptive possibilities open to agents. The problem applying LCS to adaptive living systems, we learned, is not so much acquiring the techniques of evolutionary computation, but rather it is designing a coupled system model that appropriately constrains the evolutionary search procedures of the LCS. Those constraints have to reflect the system being modeled and, of course, require the modeler to have a good knowledge of that system.

The LCS procedure described very briefly: The LCS methodology evolves a set of decision rules separately for each agent. Decision rules simply specify a set of environmental conditions, an action and, appended to the rule, a set of minimal statistics that allow the agent to compare the outcome of different actions used in similar circumstances (i.e., “conditions :: actions :: results”). Agents are placed in a complex, spatially explicit, simulated biophysical environment. This modeled environment supplies agents with information about the ‘conditions’ at a particular place and time. Each agent begins the simulation at a random location with a random set of decision rules; agents test rules through repeated use, selecting those that have performed well in the past, i.e., fit rules. New variations of fit rules are created through the equivalent of mutation and recombination and, in our models, through imitation that results from communication with other agents. Each agent evaluates each set of environmental circumstances according to its experience. Over time each agent’s experience leads it to choose to search familiar places and communicate with familiar people because that familiarity provides a strong sense of context and is a better guide to the likely outcome of alternative actions. This procedure results in a model environment with multiple, heterogeneous agents interacting with one another and the biophysical environment. (See Wilson et al. 2013a for a full description of the approach.) Because the agents affect the environment through their competitive actions the system's dynamics, even if initially ‘simple’ become very complex, leading to a typical dynamic fitness landscape.

Data required for implementing LCS: The models we’ve developed are comprised of two principal parts: A bioeconomic simulator and a learning classifier system. The simulator is a standard simulation and uses oceanographic and biological data required to produce a fine temporal and spatial simulation of the fishery, e.g., in the urchin fishery, the interactions of seaweed and herbivores over the course of the seasons (Johnson et al. 2012). Data requirements for the LCS part of the models are defined by the LCS rule structure and decision hierarchy, i.e., (1) kinds and circumstances of information used by agents (fishermen) and (2) ways agents partition their decisions according to their temporal and spatial scale. To acquire this information we developed an in-depth, open-ended and iterative interview methodology. Fishermen were engaged in an initial set of interviews; preliminary models were designed on the basis of those interviews. Invariably during the process of design we realized we needed to know more about one or more aspects of the process; fishermen were engaged in additional interviews, and the process of interview-design-interview-design continued until we judged the rule structure reasonably replicated fishermen’s decision process. Johnson, et al. (2012) explains the methodology in greater depth.

This evolutionary modeling approach leads us to conceptualize the overfishing problem as one in which normal profit seeking human activity leads to a progressive erosion of the organization of the natural system. The argument is summarized most completely in Wilson et al. 2013b and Johnson et al. 2012.

Specific Objectives: Our principal specific objective was to learn how to apply evolutionary computational techniques, LCS in particular, to a coupled system. This meant understanding the computational approach and learning how to acquire and integrate it with scientific and fishermen's knowledge of both the biological and the human environment.

Significant Results: Evolutionary computation is a well developed field in computer science. Applications of the approach tend to emphasize optimization of hard, but well defined problems, e.g., the traveling salesman problem, management of electrical grids, and so on. Applying LCS to problems of learning and adaptation in a complex social-ecological system is a significant departure from the usual application of LCS. As we use it, LCS is a way to model non-equilibrating, evolutionary processes. This is important because an understanding of the computational mechanisms that produce this kind of dynamic allows one to conceptualize processes that are otherwise only vague constructs. In other words, understanding the computational methodology allows one to more readily conceive of evolutionary dynamics without explicit recourse to the computational process itself.

There are two modifications of the LCS methodology that we feel are the key to modeling learning and adaptation in complex systems. These modifications address problems that usually limit the scope of questions that might be addressed with evolutionary computation. The **first concerns the size of the agent’s search space**. In a complex environment, the amount of information an agent might acquire is extremely large. If the agent were to examine all the circumstances and all the possible actions that might be taken, it would face an intractable problem. The problem is very much like the problem we all face every day; if one tried to consider all the possible situations in one’s environment one would be overwhelmed with the costs of acquiring and analyzing all that information and would confront an impossibly large problem.

Fishermen (and most people) tend to avoid this problem by partitioning their environment according to temporal and spatial scale; they consider immediate term information about their very local environment; then, on the basis of their experience and what they have learned from others, they compare the opportunities in that circumstance with the opportunities they believe, might exist at broader scales. If they decide opportunities at a broader temporal and spatial scale are better, they reach this conclusion based upon knowledge that is slower paced, longer term and with a broader geographical scope. In this way, they build a hierarchical decision process that is very much like a decision tree except that it is carefully scaled by time and space.

The design of our models imitates this decision process. At each level of the hierarchy we create an LCS in which the information used by the agent is focused on a particular temporal/spatial scale, e.g., very local and immediate term or broad scale and long term. This way of partitioning the agent’s decision problem reduces the agent’s search space by several orders of magnitude. For example, using one instance in our modeling history, the search space for a non-hierarchical model is approximately 14 trillion. For the corresponding (four level) hierarchical model it is about 6,000.

This reduction in search space is computationally efficient, but more important, if the agent's time (or the other resources it uses for search) are limited, the agent can search the (partitioned) environment at a rate that is faster than the rate at which the environment itself changes. This gives the agent the ability to observe regularities and, thus, creates the possibility of learning and adaptation; it also means that this method of modeling can be applied to more complex situations than otherwise. Partitioning the problem in this way also transforms the problem of learning into an economic problem in the sense that the agent has to find a way to economize on the time and other resources it uses for search and communication.

The second closely related problem concerns the agent's choice of where to search and how to value the information it acquires while searching. In other words, to make an intendedly rational decision the agent must have a way to determine the relative value of the opportunities open to it. In the LCS approach agents acquire this sense of relative value through experience. Over time their own autonomous search and the information they acquire from communications with others provides them with experience about what works and what does not in what kinds of conditions. But the knowledge agents acquire in this way is limited to that part of the environment and those other agents with whom they have experience. This experience gives them a sense of familiarity and context and is the basis for their understanding of the likely value of different courses of action.

In our models we track agents' familiarity according to how often they encounter other agents and particular parts of the natural environment. We assume that familiarity leads to greater accuracy in the interpretation of information conveyed by particular observations or communications with other agents. Agents use information obtained this way to make decisions about what actions to take; they receive feedback, i.e., payoffs, that reflect the value of those actions. Accurate communications guide their actions better than inaccurate information; as a result, because good information about bad opportunities is as valuable as good information about good opportunities, agents learn to target their communications and observations towards agents and parts of the environment from which they receive the most accurate information. This leads them to repeat communications with those same agents and to a preference for acting in familiar parts of their environment where they understand the context and can better interpret the meaning of messages and observations. In complex environments, this simple mechanism creates positive feedback that leads agents to the establishment of persistent individual and group relationships. In effect, the essence of the self-organizing mechanism is the economizing behavior of individual agents.

Both of these modifications of the LCS methodology make it possible to model the way learning and adaptation by individual agents leads to the emergence of order. We believe this opens the door for a significant new methodology that allows the rigorous exploration of complex and adaptive systems. In fisheries, this perspective has led us to a significantly different view of the overfishing problem, namely, that fishing is a process that erodes the self-organizing structure of the natural system. We are currently developing a journal article fleshing out this view, have a model that is complete and awaiting submission and have submitted a new CNH proposal along the same lines.

Key outcomes or Other achievements:

The modeling/methodological advances described above generate a useful definition of the opportunity cost of information. There is close to universal agreement about importance of information for almost all social and economic activity, yet the economics profession has no way to characterize the acquisition of knowledge as a fundamental economic process. That is, it is common to address questions such as the value of going to college, of visiting one more car dealer or something similar in terms of the costs and benefits of the knowledge that is acquired. There is a good deal of interest in the nature of exchange when the parties have asymmetrical knowledge and there is widespread agreement that increases in GDP are largely due to improved knowledge in the workforce and that the dynamics of invention and innovation are driven by the knowledge of the principal actors. However, there is no theoretical description of how individual decisions about the acquisition of information and knowledge emerge or affect the allocation of resources, growth or almost any aggregate economic measures one might consider.

Consequently, it is of interest to us that the evolutionary approach in our models led us (forced us) to frame the agent's decision problem as the path dependent acquisition of knowledge; that is, one in which the kind of information acquired at one point, or the opportunities perceived, is a function of previously acquired information and knowledge. In even the moderately complex environment created in our models this leads to heterogeneous agents each of which values each bit of information differently, depending on the agent's history. As a result, if one were to consider information as an economic good, i.e., a scarce commodity, it would be the ultimate differentiated product — the same message having a different meaning, value and cost to each agent. The implication is unremitting heterogeneity with always present asymmetries in knowledge and pervasive uncertainty.

Agents in these models are boundedly rational. Adaptation to these circumstances leads individuals behave in such a way that leads to persistent individual and social relationships, including markets. Generally our models point to very different forms of social and economic organization depending on the cost of acquiring useful knowledge (Wilson, et al 2013a, 2013b). That cost depends upon the dynamic properties of the environment in which agents live. In stable, easy to predict environments the cost of knowledge is relatively low and there is little incentive for cooperative behavior. In random environments the value of any knowledge (beyond the knowledge of randomness) is close to zero and there is, here also, little value in cooperative behavior. In complex organized environments, on the other hand, the cost of acquiring knowledge is positive and there is value to be gained by communication with other agents who possess knowledge not known by the agent. Because of the positive feedback associated with shared information, there is a strong tendency for the development of persistent individual and group relationships. We believe these conclusions are broadly applicable and not simply an economic phenomenon peculiar to fisheries. Wilson et al. 2013a and 2013b emphasize these ideas as applied to the three fisheries studied in this project. An additional paper emphasizing the broader, non-fisheries application of the idea is in preparation.

In the fisheries we looked at, the very different circumstances of search have led to very different social and biological outcomes. From the perspective of an individual fisherman in the urchin or the groundfishery the very fine temporal and spatial scale of patterns tend to be very irregular, almost random, especially because other fishermen have a significant affect upon those patterns. At this fine scale there is little fishermen gain from information sharing and, consequently, little or no social structure. If groups arise their duration is rather limited and, by and large, there is little or no development of the kind of self-organized civil foundation that facilitates agreements about collective action. In the lobster fishery, on the other hand, the circumstances of lobster and lobstermen's behavior tend to be irregular but not to the point of randomness. Lobster movements tend to be relatively localized; they tend to be fairly predictable at a moderate scale (several miles) but are less so at finer scale (hundreds of meters). It is fine scale predictability that counts for a fishermen; consequently, because lobsters don't move so fast fishermen find it worthwhile to share information about current hot spots. In short, the biophysical characteristics of the resource lead to relatively stable, persistent groups and, from that, a civil foundation that facilitates agreements about conservation. These findings are strongly consistent with the history of the three fisheries.

Another surprising outcome of these models is the way this kind of evolutionary process leads to a very efficient spatial/temporal allocation of fishing activity. For the lobster fishery, we were able to obtain a data set that recorded very fine scale information from 44 fishermen for 1 million trap hauls and catch by depth (location) and day of the year. This data shows a remarkably effective allocation of traps in space and time. Although not perfect it would be very hard to place traps in a way that led to a more efficient outcome. The same result obtains in the model outcomes. In both instances we assume these outcomes are the product of information sharing among what would otherwise be inefficient fishermen/agents. These results are consistent with a broader qualitative line of reasoning in economics in which it is believed that communications among self-interested agents, usually through the price mechanism, lead to a high level of self-organized aggregate efficiency.

The spatial efficiency of harvesting has important implications for the appropriate scale of managment. Costly information and travel costs lead profit driven fishermen to prefer least cost locations for harvesting. If fish populations are characterized by metapopulations with patchy distributions as seems to be true among most finfish, then fishermen's preferences will lead to different rates of harvest among the components of the metapopulation. Precautionary quotas and other regulatory restraints designed for the entire metapopulation are not likely to protect the components of the population. Furthermore, if those components are characterized by minimum viable population sizes quotas based upon a mistaken assumption of a panmictic population is very risky management that increases the chances of local extirpations and erosion of system organization. Put differently, the spatial selectivity of fishermen's behavior means that a precautionary approach to management is dependent the 'model' that best fits the population. Broad scale quotas may protect panmictic populations but not the components of metapopulations (Ying et al. 2011; Zang, et al. 2011; Wilson et al 2013c). We have finished an agent-based (non-evolutionary) model of this process and are currently writing up an article for submission to a professional journal. Finally, a very large proportion of the journal articles produced in this project (see publications list) are variations on the theme of adaptation to complex human and natural spatial structure. Generally these publications are concerned with policy the implications of scale mismatches

* What opportunities for training and professional development has the project provided?

The project initiated a new graduate level course in the dynamics of coupled natural and human systems (SMS 552) and an on-going multi-department seminar in complex adaptive systems. Over the course of the project approximately 17 faculty and an equal number of graduate students participated in the seminar. Two undergraduate, nine graduate and one post-doctoral student (listed below) were directly employed in the project.

1. Morehead, Graham, MS Graduate Student (research assistant), finished, Computer Sciences

Morehead, Graham Andrew, and Roy M. Turner. 2014. *A Complex-Systems Approach to Simulating the Sea Urchin*

Ecology. Thesis (M.S.) in Computer Science--University of Maine, 2014.

2. Hayes, Peter, PhD Graduate Student (research assistant), continuing, School of Marine Sciences

3. Hill, Jack, MS Graduate Student (research assistant), continuing, School of Marine Sciences

A Computational And Mathematical Description Of A Population On A Dynamic Landscape Driven By The Voter Model. Jack Leslie Hill. Thesis (M.S.) in Mathematics. Advisor: Dr. David Hiebeler .— University of Maine 2014

4. **Kersula, Michael,** MS Graduate Student (research assistant), finished, School of Marine Sciences

Kersula, Michael E., James Wilson, and Yong Chen. 2014. *Scale-Dependent Structure in Spatial and Temporal Variation in Fish and Fishermen's Behavior*. Thesis (M.S.) in Marine Biology--University of Maine, 2014.

5. **Stoll, Joshua,** PhD Graduate Student (research assistant), continuing, School of Marine Sciences

6. **Whitsel Lawrence,** PhD Graduate Student (research assistant), finished, Computer Sciences

Whitsel, Larry T., and Roy M. Turner. 2013. *A Context-Based Approach to Detecting Miscreant Agent Behavior in Open Multiagent Systems*. Thesis (Ph.D.) in Computer Science--University of Maine, 2013.

7. **Wilson, Chris,** PhD Graduate Student (research assistant), continuing, Computer Sciences

8. **Hayden, Anne,** PhD Graduate Student (research assistant), continuing, Interdisciplinay PhD.

9. **Tsebro, Yuriy,** Undergraduate, Univ. of Southern Maine (research assistant), departed, Computer Sciences

10. **Leeman, Nick,** Undergraduate, UMaine Augusta (research assistant), continuing, Computer Sciences

11. **Yan, Liying,** Postdoctoral Student, departed 2010, School of Marine Sciences

12. **Cleaver, Caitlin,** MS Graduate Student (research assistant), finished, School of Marine Sciences

Cleaver, Caitlin, James A. Wilson, and Robert S. Steneck. 2014. *The Maine Green Sea Urchin Fishery: Scale Mismatches, Trophic Connectivity and Resilience*. Thesis (M.S.) in Marine Biology and Marine Policy--University of Maine, 2014.

* How have the results been disseminated to communities of interest?

Project members have worked closely with three NGOs concerned with the applied, fine scale management of marine resources. They include the Penobscot East Resource Center, the Downeast Fisheries Alliance and the Fish Locally collaborative. We have helped them prepare funding proposals to NOAA and to various private foundations in support their work and have advised them on scientific matters especially as they relate to matters of scale and management. Two project members are on the board of directors of Penobscot East; one chairs the scientific subcommittee of the organization. Project members have actively participated with these NGOs and the Maine Department of Marine Resources in the exploration of a new multispecies, ecosystem-based approach to licensing in the state's fisheries and have generally contributed substantial time and effort to pro-bono consulting for the State and NGOs.

Products

Books

Book Chapters

Conference Papers and Presentations

Inventions

Journals

Anne Hayden, James Acheson, Michael Kersula and James Wilson (2012). Spatial and Temporal Patterns in the Cod Fisheries of the North Atlantic. *Conservation and Society*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

JA Wilson; J Acheson; T Johnson (2013). The cost of useful knowledge and collective action in three fisheries. *Ecological Economics*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.ecolecon.2013.09.012

Licenses

Other Products

Other Publications

Patents

Technologies or Techniques

Generalized code for implementing hierarchical learning classifier systems. The code is derived from the code used to model the lobster fishery; however, it has been made generic so that it can be easily used by other modelers.

The code is publicly available on the OpenABM website: https://www.openabm.org.

The code was developed by Larry Whitsel; the submission to OpenABM was prepared by Nickolas Leeman.

Thesis/Dissertations

Graham Morehead. *A Complex-Systems Approach to Simulating the Sea Urchin Ecology*. (2014). University of Maine. Acknowledgement of Federal Support = Yes

Larry Whitsel. *A Context-Based Approach to Detecting Miscreant Agent Behavior in Open Multiagent Systems*. (2014). University of Maine. Acknowledgement of Federal Support = Yes

Michael Kersula. *Scale-Dependent Structure in Spatial and Temporal Variation in Fish and Fishermen's Behavior*. (2013). University of Maine. Acknowledgement of Federal Support = Yes

Caitlin Cleaver. *The Maine Green Sea Urchin Fishery: Scale Mismatches, Trophic Connectivity and Resilience*. (2013). University of Maine. Acknowledgement of Federal Support = Yes

Websites

Supporting Files

Filename	Description	Uploaded By	Uploaded On
Fine Scale Dynamics - pubs and present.pdf	At the top of this page is the statement "Products from your last annual report have been added to this report..." When I preview this final report those publications do not appear. This may be intended; however, in case it is not I have uploaded a list o	James Wilson	12/28/2014

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked

Wilson, James	PD/PI	2
Acheson, James	Co PD/PI	1
Chen, Yong	Co PD/PI	1
Johnson, Teresa	Co PD/PI	1
Steneck, Robert	Co PD/PI	1
Congdon, Clare	Faculty	1
Turner, Roy	Faculty	1
Vadas, Robert	Faculty	1
Yan, Liying	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Cleaver, Caitlin	Graduate Student (research assistant)	12
Graham, Morehead	Graduate Student (research assistant)	12
Hayes, Peter	Graduate Student (research assistant)	12
Hill, Jack	Graduate Student (research assistant)	12
Kersula, Michael	Graduate Student (research assistant)	12
Stoll, Joshua	Graduate Student (research assistant)	12
Whitsel, Lawrence	Graduate Student (research assistant)	12
Wilson, Chris	Graduate Student (research assistant)	12
Tsebro, Yuriy	Undergraduate Student	6
Ames, Edward	Consultant	8

Full details of individuals who have worked on the project:

James A Wilson
Email: jwilson@maine.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 2

Contribution to the Project: Lead PI, model development, field work, project management

Funding Support: NSF, Maine Agricultural and Forestry Experiment Station

International Collaboration: No
International Travel: No

James M Acheson
Email: acheson@maine.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Field work, interviews, model design process

Funding Support: NSF

International Collaboration: No
International Travel: No

Yong Chen
Email: ychen@maine.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Modeling and statistical expertise

Funding Support: NSF

International Collaboration: No
International Travel: No

Teresa Johnson
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Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Field work, model design

Funding Support: NSF

International Collaboration: No
International Travel: No

Robert S Steneck
Email: steneck@maine.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: modeling design

Funding Support: NSF

International Collaboration: No
International Travel: No

Clare B Congdon
Email: congdon@usm.maine.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Senior Personnel

Funding Support: Other - USM

International Collaboration: No
International Travel: No

Roy Turner
Email: rmt@umcs.maine.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Advising role in development of computational aspect of all fishery models

Funding Support: Other

International Collaboration: No
International Travel: No

Robert Vadas
Email: vadas@maine.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Advising role on development of biophysical part of urchin model

Funding Support: Other

International Collaboration: No
International Travel: No

Liying Yan
Email: liying.yan@gmail.com
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 6

Contribution to the Project: Development of lobster model

Funding Support: NSF and ???

International Collaboration: No
International Travel: No

Caitlin Cleaver
Email: caitlin.cleaver@maine.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Interviews with fishers, scientists, and managers for development of urchin model

Funding Support: NSF

International Collaboration: No
International Travel: No

Morehead Graham
Email: graham.morehead@maine.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Urchin model development and analysis

Funding Support: NSF

International Collaboration: No
International Travel: No

Peter Hayes
Email: peter.hayes@maine.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Development of general MASON software for all models; LCS design and coding

Funding Support: NSF and NOAA

International Collaboration: No
International Travel: No

Jack L Hill
Email: jack.hill@maine.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Reworking of lobster model; development of groundfish model metapopulation model

Funding Support: NSF

International Collaboration: No
International Travel: No

Michael E Kersula
Email: michael.kersula@maine.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Oral history collection, other interviews with groundfishers, groundfish model development, participant-observation in groundfish and salmon fisheries

Funding Support: NSF

International Collaboration: No
International Travel: No

Joshua Stoll
Email: Joshua.Stoll@maine.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Josh is a PhD student working on the governance and community outreach part of the project.

Funding Support: NSF

International Collaboration: No
International Travel: No

Lawrence Whitsel
Email: larry.whitsel@maine.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: computer science grad student. Development of lobster, urchin, and groundfish models

Funding Support: NSF

International Collaboration: No
International Travel: No

Chris L Wilson
Email: cwilsn28@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Urchin and groundfish model development, implementation, and examination of model outputs

Funding Support: NSF

International Collaboration: No
International Travel: No

Yuriy Tsebro
Email: yuriy.tsebro@maine.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 6

Contribution to the Project: Assistance with development of models

Funding Support: NSF

International Collaboration: No
International Travel: No

Edward P Ames
Email: tedames@penobscoteast.org
Most Senior Project Role: Consultant
Nearest Person Month Worked: 8

Contribution to the Project: Advising role in development of all fishery models

Funding Support: NSF, Penobscot East Resource Center

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Penobscot East Resource Center	Other Nonprofits	Stonington, ME

Full details of organizations that have been involved as partners:

Penobscot East Resource Center

Organization Type: Other Nonprofits
Organization Location: Stonington, ME

Partner's Contribution to the Project:
Facilities
Collaborative Research
Personnel Exchanges

More Detail on Partner and Contribution: Partner is actively involved in efforts (with NOAA/NMFS) to bring localized science and governance to the ocean region called the Eastern Maine Coastal Current. Consequently, we share a strong common interest in the finer scale aspects of fisheries and fisheries management. Our graduate students use their facilities; their staff works directly with the project and, in one case, their staff member is on a student's committee. Project members have helped prepare proposals by Penobscot East, have collaborated on research and helped organize two scientific meetings sponsored by Penobscot East. Two project members serve on the board and on the scientific subcommittee of the board.

What other collaborators or contacts have been involved?

NO

Impacts

What is the impact on the development of the principal discipline(s) of the project?

The modeling methodology developed in this study is a significant departure from existing modeling methods in the social and ecological disciplines. The ability of agents to learn and adapt is the fundamental attribute that sets off living from non-living systems. Yet almost all modeling methods of living systems require the modeler to specify the expected conditional behavior of agents, i.e., what they can learn and how they might adapt in the environment being modeled, as if that behavior was already known from previous behavior. An LCS relies instead on modelers knowledge of the kinds of information about the environment that are important to the agent's decision making. Rather than specifying the agents actions, the LCS uses evolutionary search to find actions that are consistent with the agent's self interest and the environment in which it operates. In this sense it is a fundamentally different way to model the behavior of agents in living systems.

The evolutionary modeling techniques we have developed are modifications of methods used in artificial intelligence. They allow modeling of individual learning and adaptation. The specific method we have used is called a learning classifier system (LCS). It is a computational approach intended to model the way self-organization emerges from individual learning and adaptation. The significant modifications we have made to LCS allow adaptation of the general method to large complex systems. Those two modifications are (1) a hierarchical decision process that radically reduces the agent's search space, making it possible for agents to adapt and learn in large complex environments, and (2) a method for simulating accuracy in communication, or knowledge of context, as a function of an agent's frequency of encounter with other agents or environments.

Together these two modifications make the use of evolutionary computation in a complex environment tractable. This enables modeling of the emergence of (1) boundedly rational individuals, (2) individual agent relationships, (3) agent preferences for particular places and (4) multiple persistent groups and (5) a self-organized, nearly decomposed, spatially distributed coupled system.

What is the impact on other disciplines?

The methods we describe here are interdisciplinary; they apply to almost all the disciplines that address living systems. We apply them to ecological and human social systems. We believe, but cannot affirm, that the computational techniques — the conceptual approaches — we have developed can travel back to computer science and expand the scope of problems that might be approach with computation.

What is the impact on the development of human resources?

The project has contributed in whole or in part to the support of 11 (MS and PhD) graduate students in marine sciences, social sciences, mathematics and computer sciences. Each student has had a significant role in the project development and has a reasonably thorough education in fisheries and in the theory of complex adaptive systems.

Graudate students and faculty on the project have worked out rather difficult procedures for interdisciplinary work involving ecological, social scientists and computer scientists.

The project led to the establishment of one graduate level course in marine sciences — SMS 552 Coupled Natural and Human Systems — and an on-going graduate student/faculty seminar in complex adaptive systems and evolution.

What is the impact on physical resources that form infrastructure?

Nothing to report.

What is the impact on institutional resources that form infrastructure?

Nothing to report.

What is the impact on information resources that form infrastructure?

Nothing to report.

What is the impact on technology transfer?

Nothing to report.

What is the impact on society beyond science and technology?

The motivation for this work was to better understand the circumstances in which people are able to arrive at self-governing arrangements that are able to sustain a renewable resource. In fisheries this happens very infrequently. The usual outcome is either a free-for-all in which the resource is almost always severely depleted or a government imposed top down solution in which the police power of the state is used to restrain the free-for-all. Occasionally, as in the lobster fishery, individuals do arrive at local self-governing arrangements that restrain the free-for-all; but local self-governance that works requires the explcit support, or endorsement, of higher level government. The implications are clearly important beyond the bounds of fisheries.

In our work we looked at three fisheries — lobster, sea urchins and groundfish — that are harvested by the same communities. In the lobster fishery self-governance took hold but only after a devastating depletion of the fishery in the early part of the last century. However, since the middle of the last century the fishery has been largely self-governed and persistently successful with both sustainable populations and harvests. In the urchin and groundfisheries the same people and communities were not able to arrive at self-governing arrangements in spite of intimate knowledge of the success of the lobster fishery. For the last twenty years both fisheries have been severely depleted in spite of attempts by government to impose top-down solutions.

To try to better understand these different outcomes we focused our attention on the motivations of fishermen and the way they interact with the ecology of the system at a very fine scale. The question, of course, was why were people able to arrive at self-governing arrangment in the lobster fishery and not the others? What we found was that the kind of search and learning problem — the ways people had to go about finding useful knowledge — differed greatly in the three fisheries. In the lobster fishery the habits of the animal and the technology of harvest put fishermen in nearly daily contact with one another. The persistence of these contacts contributed to their understanding of the results of their collective action and, with the help of the State, they were able to forge local self-governing arrangements that largely address the problem of depletion. In the urchin and groundfisheries the cost and the character of the search problem separated fishermen and led to a continuing free-for-all and severe depletion.

Our analysis of these fine scale differences led us to focus on the adaptive response of people to the different kinds of information problems posed by each fishery. To do this we chose to model these fisheries using methods imported from computer science and unique to social and ecological sciences. We employ these models to look at the way individual fishermen learn from experience, i.e., how they acquire valuable knowledge. The models themselves empoly an evolutionary approach to gaining experience.

The conclusions from the models are that the incentives and the ability to engage in self-governing arrangements are very low in stable, predictable environments and in predictably random environments. In both these situations there is little individuals can learn from one another and little reason to develop the kinds of persistent relationships that are the foundation of self-governance. In complex environments, however, predictability is difficult but possible if the individual focuses on a place or a specialty. In these circumstances the individual usually gains a great deal through the kind of information sharing that comes from persistent, long-term relationships.

Changes/Problems

Changes in approach and reason for change

The post-doc originally part of the project, Liying Yan, had to leave because of family obligations. We were not able to find a suitable replacement - a computer scientist with a marine science background - and eventually shifted staffing emphasis to graduate students.

Actual or Anticipated problems or delays and actions or plans to resolve them

The hiring delays in the shift described above slowed the project by about one year.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.