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Managing Water in the West

Technical Memorandum Number EC 2008-05

Introduction to Agent Based Modeling for Recreation Economic Analysis

U.S. Department of the Interior
Bureau of Reclamation

September 2008

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Introduction to Agent Based Modeling for Recreation Economic Analysis

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U.S. Department of the Interior
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Any remaining errors are the sole responsibility of the author.

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Abstract

The focus of this manual is on Agent based models (ABMs) and the mechanics of their application for recreational economic analysis. ABMs are used to simulate the actions and interactions of autonomous individual recreators. The aggregate behavior and interactions of these individual agents can provide unforeseen insights. The deployment and use of the NetLogo ABM platform and its use in the construction of an example recreation model are described. The recreation ABM model described here represents water-based recreation in Northeastern Puerto Rico. It was developed in collaboration with NSF researchers engaged in a larger ongoing research application. Some results are reported and the strengths and weaknesses of recreation ABM modeling are described.

Purpose

The purpose of this document is to convey a conceptual and analytic understanding of agent based modeling (ABM) and its application for recreation economic analysis. An example application is described, coded and the results described. Some observations on the process, the strengths of ABM and the weakness of ABM are provided. While by no means an exhaustive treatment of the subject, some of the difficulties and associated pitfalls are discussed. A number of useful references are furnished for further study.

What is Agent Based Modeling (ABM)?

An agent-based model (ABM) is a computational model for simulating the actions and interactions of autonomous individuals. ABMs are particularly valuable because the can be used to assess the effects of aggregate behavior on the system as a whole. ABMs combine some elements of game theory, complex adaptive systems, sociology and evolutionary programming.

ABMs represent the simultaneous actions of multiple agents, in an attempt to re-create and predict the actions of complex phenomena. The process is built on a "bottom to top" approach based on these individual agents. Each agent is endowed with simple rules governing their activities. Examples of agent rule sets include rules governing movement, food acquisition, economic gain, social status and knowledge. Each agent acts in what they perceive as their own best interest. In the process, agents may experience "learning" and adaptive behavior.

Synonyms

There are a number of terms for ABMs. The usage of these terms seems to vary by discipline, with the context and nature of the application, and the researcher. Commonly encountered synonyms include at least the following:

- individual-based models (IBM) (Grimm and Railsback 2005)
- agent models (AM)
- individual agent models (IAM)
- multi-agent models (MAM).
- multi-agent based simulations (MABS).
- agent based computational economics (ABCE) (Tesfatsion 2006)

Some Definitions

As with any scientific pursuit, there is some professional vocabulary associated with agent based modeling and the literature which describes it. Some commonly encountered terms are defined and a brief explanation is provided below.

Agents

An agent is a computational device which represents an individual organism or entity. These agents may represent different species or entities in the model and individual's of that specie or entity. For example, in an agent based model of a stream, there may be brown trout agents and brook trout agents. Thousands of individual agents may make up the population of each of these species.

Emergent Properties

The term "emergent properties" has been coined to describe unforeseen and unpredicted interactions which may arise as agent based simulations are undertaken. Typically, these behaviors and interactions cannot be predicted, foreseen, or deduced from *a priori* analysis of the simple rule sets which govern individual agent interactions.

ABM Applications

ABMs have been used since the late 1970s to simulate a variety of ecological, social, economic, computing, business and engineering problems. The range of

topics explored with ABMs is vast and amazingly ingenious. Selected examples of ABM applications include segregation (Schelling 1978)[1], abstract human societies (Epstein and Axtell 1997), simulation of ancient societies (Kohler, Gumerman and Reynolds 2005), flocking behavior in birds (Reynolds 1987), fish schooling and migration (Hubbard et al 2004, Parrish, Viscido and Grunbaum 2002), foraging by fish (Anderson 2002), habitat use by endangered fish in the Colorado River ecosystem (Grand et al 2006), supplier behavior in electricity markets (Amin 2002), water catchment management (Becu et al 2003), deforestation (Manson and Evans 2007), aggregate macroeconomic behavior (Blake and Tesfatsion 2008), consumer market behavior (Garifullin, Borshchev and Popkov 2007), civil violence (Epstein 2002), as well as traffic congestion and the spread of epidemics in the population (Toroczkai and Eubank 2005).

In these and a huge number of other disparate ABM applications, the system is simulated by the aggregate behavior of individual agents, their joint and individual interconnections.

Recreation Applications of ABM

ABMs evolved from simulation models which have a long history in the context of recreational analysis (see Van Wagtendonk and Cole 2005). In contrast to traditional simulation models, ABMs typically characterize individual recreators, or a group of recreators (such as a hiking party), and they are spatially and temporally specific.

In many ways, the advent of the microcomputer, facilitated the development and widespread application of simulation models, especially ABMs. Despite the plethora of ABM applications to other topics, the application of ABMs to recreation problems is a relatively recent occurrence. The vast majority of published ABM recreation applications have appeared in the last 10 years.

Although there are surely prior recreation studies, the application of ABMs by Gimblett and Roberts (2000) to river recreation in the Grand Canyon was the first to be brought to our attention.

Gimblett and Roberts (2000) used an ABM to simulate the downstream movement of river runners on the Colorado River in the Grand Canyon. Using simple rules, the river runner agents selected campsites and stopped at attraction points along the river. This model was used by the National Park Service to help

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[1] Schelling was awarded the 2005 Nobel Prize in Economics for his research on game theory and his pioneering work in agent based modeling. An interesting account of the contributions made by Schelling, Axtell, Epstein, Dean and Gummerman to agent based modeling can be found in Raugh (2002).

assess alternative river management plans. Further descriptions of this model, its features and the analyses undertaken with it can be found in Roberts and Bieri (2001) and Roberts, Stallman and Bieri (2002).

Gimblett, Daniel and Meitner (2000) describe a prototype computer simulation system they named the Recreation Behavior Simulator (RBsim)[2]. This agent based model was developed to study the affects of time and space on levels of use in wilderness settings. It was used as a tool to examine the number of encounters in space and time under varying use scenarios in Broken Arrow Canyon, Sedona, Arizona.

Gimblett et al (2004) describe a project whose focus is on a dispersed recreation--backpacking trips and commercial packstock operations in the John Muir Wilderness in the Sierra Nevada Mountains in California. They discuss data collection aimed at constructing agent profiles and behavior rules. These rules would then be incorporated into a dynamic, agent based model representing the spatial distribution of visitation.

Zhang and Levinson (2004) developed an agent-based travel demand model. Travel demands emerged from the interactions of three types of agents in the transportation system. Their ABM distributes trips from traveler origins to destinations. Using simple rules, traveler agent behaviors efficiently solved complicated transportation problems inherent in their model.

Cavens et al (2004) employed an ABM to simulate the behavior of hikers in the Swiss Alps and how this behavior was influenced by landscape amenities. They constructed a model simulating the activities of individual hikers within a detailed 3D synthetic landscape in which the terrain, vegetation communities, structures, path and road networks and information aids such as signage were characterized. "Various landscape metrics are calculated based on these representations, including visual quality indicators such as view composition, enclosure, and depth of view. These metrics are evaluated over the course of an agent's hike, and integrated with more traditional parameters (such as hike distance, steepness, congestion and availability of amenities)…" during the simulation.

Cole 2005 reviews 12 relatively recent studies based on recreation simulation models. Of these, 5 were ABM applications. In addition to citing some of the same studies cited in this document, Cole (2005) describes 3 other recreational studies. This source contains short descriptions of ABMs applied to recreation at the Port Campbell National Park in Australia, the Misty Fjords National Monument on the Tongass National Forest in Alaska and the Bighorn Crags Portion of the Frank Church, River of No Return Wilderness.

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[2] A more extensive and up-to-date description of RBsim can be found at: http://www.srnr.arizona.edu/~gimblett/rbsim.html (accessed on 07/10/2008).

Anwar, Parrot and Marceau (2007) developed an ABM model to investigate the interaction of whale watching boats and whales in the Saguenay St. Lawrence Marine Park in Quebec. The primary objective of the project was to explore how different decision strategies of the whale-watching boat operators, exploiting a common-property resource, can influence marine mammals. The authors reported the model illustrates that the cooperative behaviour of the boat agents generates a greater aggregate benefits when compared to non-cooperative behaviour; however, it creates higher risks for the marine mammals. Ongoing enhancements will make the model more useful as a management tool.

ABMs and New Recreation Sites

One of the more vexing recreation research questions is how to estimate visitor use and economic value for sites that do not currently exist. In the planning context, the construction of new recreation facilities, such as reservoirs, or new recreation access points, such as launch ramps, can readily be envisioned. Planners, engineers and economists may hypothesize that these new facilities will lead to increased recreation use, increased economic value of recreation and increased local expenditures. However, the operative question is how to quantitatively estimate the extent of this use and the net increase in economic value which results, if any.

The introduction of new facilities or access points may well result in increased recreation use and value at those sites. However, economic theory and many applied recreation studies suggest there are other considerations. Comprehensive studies provide evidence that some proportion of this visitation is truly new recreation use[3], but some percentage of the visitation represents substitution from other sites. A systematic and responsible economic assessment must account for potential decreases in recreation use, economic value and regional expenditures at existing sites, if any.

Current approaches for estimating recreation use and economic value are built on either observations of existing behavior or on respondent reported contingent behavior. Random utility models (RUMs) and travel cost models (TCMs) make up the former category while contingent valuation models (CVMs) and conjoint models (CMs) comprise the later category of tools. Typically (and there are some exceptions), these models are employed to simulate the effects of changes in site parameters under management control at existing sites. Very few of these models were designed to allow for the estimation of recreation use and value of both nonexistent and current recreation sites.

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[3] Recreation by individuals who did not previously recreate or increased recreation by existing recreators.

In cases where the envisioned recreation sites do not yet exist, estimation of their future (net) incremental effects remains problematic.

Agent based modeling is a promising approach for estimating recreation use and value for sites that do not currently exist. ABMs simulate the behavior of individual recreators and their choice of recreation site is encapsulated by simple rules. Presuming these rules are based on replicable site characteristics, for example on the travel time and travel cost to the site, some measure of site quality, ease of physical access and so forth, construction of plausible measures for hypothetical sites is straightforward. The individual and aggregate behavior of recreators in the presence of these hypothetical sites can then be simulated. Comparing the "with new site" and "without new site" results should yield useful insights about the recreation use and value across the spectrum of recreation site opportunities.

ABM Software Tools

At the present time there are a wide variety of software tools for ABM. These span the gamut from open source freeware to proprietary, are built with a variety of programming languages, including Java, C++, C, LISP and others, and are more or less suitable for various types of ABM based simulations.

An incomplete listing of the available ABM software platforms includes the following (in alphabetical order):

- AnyLogic (www.xjtek.com/anylogic)
- CORMAS (http://cormas.cirad.fr/indexeng.htm)
- Mason (http://cs.gmu.edu/~eclab/projects/mason)
- NetLogo (http://ccl.northwestern.edu/netlogo)
- RePast (http://repast.sourceforge.net)
- StarLogo (http://education.mit.edu/starlogo)
- Swarm (www.swarm.org/wiki/Main_Page)

Leigh Tesfatsion's "Agent-based Computational Economics" site (www.econ.iastate.edu/tesfatsi/acecode.htm) includes a description of these and many other ABM software platforms.

Each ABM platform has particular strengths for specific applications. Some are clearly designed for social science simulations, others primarily for ecological modeling and still others are very generic. Their ease of use and cost is quite variable. A researcher's choice of ABM software platform for a specific application may have nontrivial consequences. Recent, readily obtainable assessments and comparisons of the available ABM platforms are provided by

Castle and Crooks (2006), Railsback, Lytinen and Jackson (2006), Tobias and Hofmann (2004) and Gilbert and Bankes (2002).

Although it is certainly possible to custom develop software for a particular ABM application, a number of experienced researchers suggest this is ill-advised and inefficient. Grimm and Railsback (2005) describe some of the software development issues which must be considered. The vast majority of researchers recommend the use of established ABM software platform. This helps to ensure the effort is replicable and verifiable.

NetLogo 4.0

NetLogo (Wilensky 1999) was selected for the development and prototyping of the recreation template described in this document. NetLogo is a descendant of StarLogo, a cross-platform modeling and simulation environment from the Center for Connected Learning and Computer-Based Modeling (CCL), Northwestern University, Evanston, Illinois. NetLogo comes with a library of sample models and some code examples. NetLogo is perhaps the most widely used ABM software and it has been employed by researchers in variety of social and natural science disciplines.

NetLogo's primary design objective is ease of use. Its programming language includes many high-level structures and primitives that reduce the amount of programming effort required. The NetLogo language contains many of the control and data structure capabilities which are found in a standard programming language.

Railsback, Lytinen and Jackson (2006) strongly recommend NetLogo for, "... for prototyping models that may later be implemented in lower-level platforms: starting to build a model in NetLogo can be a quick and thorough way to explore design decisions."

Observations on NetLogo Platform

The purpose of this section of the document is to record some comments, thoughts and observations on the NetLogo ABM software platform. Since Version 4 of NetLogo was introduced early in the life-cycle of this project, most of the comments which follow pertain to that software personality.

The NetLogo software framework is cross-platform compatible. There are versions available for the Apple Macintosh, Microsoft Windows and Linux operating systems (OSs). Presumably, NetLogo programs written on one OS can

be run on any of these other OSs. Admittedly, this particular feature of NetLogo was not fully tested as part of this project. Some related compatibility issues are described on the NetLogo website.

The NetLogo 4.0 software for Windows was downloaded from the NetLogo website (http://ccl.northwestern.edu/netlogo) without incident. Together with the documentation and the supporting version of the underlying Java software (bundled with it), the package constitutes about 58.2 Mb. Installation of the NetLogo software and supporting version of Java was accomplished smoothly and without incident on the Windows XP operating system. If only other software installations worked this flawlessly! One caveat—since the program and the Java software modify the registry, the user must have local administrative privileges to install this package.

NetLogo requires version 1.5.0 of Java for operation. The current Sun Java release is version 6.0 update 5. The NetLogo website describes some of the technical details required should the user wish to use NetLogo with their existing resident version of Java. Most users are advised to employ the bundled version of Java (and this appears to be good advice). Naturally, additional disk space is required to accommodate the bundled version of Java.

For reasons unknown, version 4 of NetLogo is not backward compatible with previous versions of NetLogo. Consequently, models constructed in version 3.x will not run in version 4.0, and vice versa. This feature is truly irritating and inconvenient.

Relatively extensive documentation is provided with NetLogo 4.x including a model library and some code examples. The static help system is html based and designed to be viewed in a browser. Unlike many modern applications, the NetLogo help system is not context sensitive (although it does have a reasonably good lookup capability). Although there are a number of code examples included with the installation, none of them are nearly as sophisticated as required by this project and they were of limited usefulness.

The NetLogo integrated development environment (IDE) is adequate but lacks the sophistication of commercially available IDE's and most open source programming platforms as well. The IDE has a limited number of drag and drop visual components, such as buttons, sliders and plotters. These are robust but relatively primitive in terms of their implementation, options and features. An integrated debugger is built into the IDE and identifies syntax (programmer) errors. It provides some useful information about their underlying cause. One prominent omission, and a feature which most programmers would expect to find in a modern IDE, is the error messages issued by the debugger do not reference the location where the error occurred. Only one syntax error at a time is identified.

Runtime errors are handled reasonably gracefully in NetLogo. When runtime errors occur, the IDE issues a message and the interpreter halts. However, this error message does not reference the location in the code where the error originated. Using the Windows XP operating system, certain types of runtime errors appear to cause symptoms of program/operating system instabilities to occur. These runtime errors necessitate a shut-down and restart of NetLogo, or, in more dire cases, an operating system reboot.

The NetLogo language is simple enough to use, almost bordering on too simple. There are a number of pre-built primitive objects which accomplish many programming functions. In many respects, the convenience these primitives afford is negated by the lack of effective documentation about them and what they do. Programmers with a scientific background should note that there are no arrays or matrices in the NetLogo language. These mathematical structures are replaced by sets and sets of sets. In the absence of effective documentation, or pertinent examples, using them is especially exasperating.

NetLogo, based on Java, is an interpreted language and is relatively slow in comparison to compiled languages. The speed at which it runs a simulation is fairly reasonable for small problems but the simulation speed deteriorates noticeably when the number of agents is increased. In the NetLogo recreation template, described subsequently, the actions of approximately 1500 recreators are simulated on a holiday (Monday, for the test data set). This causes a very noticeable and rather prolonged delay in the simulation, leading the uninitiated user to wonder if the computer has locked up.

A potential advantage of NetLogo is that Java applets can easily be created. These applets, which operate inside a browser, can then be distributed to other researchers, reviewers or users who don't have the NetLogo software installed on their computers but do have a resident version of Java. These applets can also be embedded in a website.

Collaboration with NSF Project

The Bureau of Reclamation enjoyed significant value added through a mutual collaboration with researchers engaged in an ongoing ABM application. The modeling effort described in this document leverages and builds upon the extensive long-term on-site research and ABM modeling work funded by the National Science Foundation (NSF) grant number 0308414. The title of this ongoing NSF project is, "Modeling Complex Interactions of Overlapping River and Road Networks in a Changing Landscape." It is referred to in this document as the "Puerto Rico Biocomplexity Project," or more simply, as the "Biocomplexity Project." This work focuses on recreation (and other) interactions with the aquatic environment in Puerto Rico.

The biocomplexity project, in turn, benefited from the collaboration with Reclamation staff. Reclamation staff, working together with principal investigators from the biocomplexity project, helped to operationalize and code some of the recreational behaviors observed during their onsite research and data collections. The recreation ABM model developed and described in this document served as a prototype for the recreation component of the larger Swarm model being developed for the biocomplexity project.

Puerto Rico Biocomplexity Project

Like most National Science Foundation efforts, the biocomplexity project is large, complex and many faceted. This section of the document provides some key background material pertinent to the Reclamation involvement in this project.

Description

The following description of the biocomplexity project has been extracted from the project website (http://biocomplexity.warnercnr.colostate.edu).

The goal of the biocomplexity project is to investigate the direct effect of roads on the natural hydrology, migration of decapods such as shrimp, and the indirect effect of roads allowing visitors to recreate in the stream, potentially affecting the habitat of the decapods as well as water quality for downstream users.

In order to address this goal, the scientists developed and tested the analytical tools needed to understand and predict the interactions and feedbacks among humans and aquatic species across a compact landscape that moves from the top of a tropical watershed to the ocean in a matter of a few miles. One organizing principle is that landscape patterns and changes in network structure and function are explained by energy and time optimizations of water flows, biota and humans. There are many ways that each subsystem individually optimizes time and/or energy, each optimization imposes constraints on related subsystems, which can then change the rules by which each operates. Through these multiple feedbacks and interactions, even individually well-understood subsystems can produce unpredictable dynamics. The research team is in the process of developing an integrated modeling framework to incorporate feedback and interactions among biotic and abiotic systems so as to accurately predict the effects of interactions of human and aquatic populations using an individual- (agent) based simulation model and the role that roads play in these systems.

The main overarching hypothesis is that an integrated individual-based model will more accurately predict environmental effects than any single physical, biotic or

social model by reducing unexplained variation. The mechanism generating this reduction in variance results from including cross-disciplinary connections and corresponding agent feedbacks to what otherwise would be missing in the individual disciplinary models (e.g. , human use as an explanatory variable in biotic systems). In order to test this hypothesis the research team is the in process of developing an integrated individual-based model of physical, biotic and social networks using energy and time optimization as a unifying principle with multiple feedbacks between networks as a framework to capture different hierarchical levels of complexity.

Field studies and calibration of sub-models are now ongoing in two adjacent watersheds in northeastern Puerto Rico that have land uses that range from high-density urban to pristine tropical rain forests. The integrated model will then be tested in a third watershed that contains the same mix of land uses found in the adjacent watersheds. Northeastern Puerto Rico is a good natural laboratory due to rapid spreading of urbanization and sub-urbanization with an associated hierarchy of road networks that modifies the natural landscape and places people closer to natural resources. Being in a coastal environment in proximity to rain forests, there is a steep land rent gradient that compresses the transitions from one land use to another. Similarly, the topographic steepness results in numerous, distinct transitions from one biological community to another in a short distance.

Studies of physical, biological and social systems will be integrated into a unified individual-based model. In this framework agents interact by a set of rules or functions. These rules describe how each type of agent (physical, biotic and human) operates. These rules include not only the direct actions of the agents, but also interactions of the agents with each other. In the past, these individual-based models were applied separately to biotic and human systems. Using an established individual-based modeling protocol called Swarm, the team will integrate the physical, biotic and human agents as interacting components of a single ecosystem. This includes modeling the operation of physical processes of river networks, the modeling of biotic organisms within these rivers and the modeling of human agents' behavior through time.

Key Research Collaborators

There are a large number of nationally and internationally renowned researchers participating in the biocomplexity project (see the project website for a complete list). Several of these researchers closely collaborated on the construction of the recreation ABM described in this document. These researchers are:

John B. Loomis	Department of Agricultural and Natural Resource Economics. Colorado State University. Ft. Collins, Colorado.

Paul W. Box — Center for Arid Lands Research. Commonwealth Scientific and Industrial Research Organization (CSIRO). Alice Springs, Australia.

Luis E. Santiago — Graduate School of Planning. University of Puerto Rico. Rio Piedras, Puerto Rico.

The Study Site

The agent based recreation model described in this document is a simplified depiction of recreation in Puerto Rico's northeastern region. This model simulates water-based recreation on the Rio Mameyes and the Rio Espiritu Santo watersheds, the majority of which are located on the El Yunque National Forest (formerly known as the Caribbean National Forest).

The following description of the study site is based almost exclusively on the description provided by Santiago, Gonzalez-Caban and Loomis (2008). The contributions of these authors is explicitly acknowledged.

The Mameyes is one of very few rivers in Puerto Rico to run through most ecosystems present in Puerto Rico, including the rain forest, the coastal flood plains, wetlands, and mangroves (Gonzalez-Caban and Loomis 1997). The river originates at 728 meters (2396 feet) above sea level in the Caribbean National Forest. Its length is estimated at 15.5 kilometers (9.7 miles), and traverses the municipalities of Rio Grande and Luquillo.

A U.S. Forest Service Visitor Center is located on the Rio Mameyes and it is the more well known of the two rivers in Puerto Rico, attracting local visitors as well as tourists from outside Puerto Rico. The Espiritu Santo, on the other hand, is visited mostly by local residents. The Espiritu Santo begins at an altitude of 740 meters (2435 feet) above sea level.

Both watersheds originate in the Caribbean National Forest (CNF), the only tropical rainforest within the USDA Forest Service National Forest system. The CNF has a land area of approximately 11,336 hectares (28,000 acres) and contains over 240 species of native trees. There are also 127 species of terrestrial vertebrates and ten species of aquatic invertebrates. The CNF is the habitat of five endangered species and one threatened species. In its rivers and other bodies of water, there are a variety of shrimp and fish species (such as *Macrobrachium carcinus* and *Agonostonoms monticola*), as well as river crabs (*Epilobocera sinuatifrons*). Its highest peak is 1077 meters (3533 feet) above sea level, and its mean temperature is 21°C (73°F).

Both rivers are characterized by bedrock stream bottoms and lush tropical forest canopy. Both the Mameyes and Espiritu Santo rivers have many small pools for swimming, wading and sitting.

A relevant management concern for this area is the high level of visitor use on the rainforest ecosystem, particularly the streams and rivers. Puerto Rico's average population density in 2005 was estimated at 440.8 inhabitants per square kilometer, or 1125.3 inhabitants per square mile. Recreation use in Puerto Rico is possibly more intensive than use in other National Forests.

The NetLogo Recreation Template

Much of the ABM work described in this document focuses on a small deceptively simple NetLogo recreation model. This recreation model is henceforth referred to as the "NetLogo recreation template". This section of the document describes the background, strategy, evolution and development of the NetLogo recreation template.

Recreation is an integral part of the Biocomplexity Project described previously. Many aspects of recreation differ fundamentally from the natural world. To increase the speed of programming and development work on the biocomplexity model, the recreation component of the model was developed in parallel with the larger physical, hydrologic and biological (Swarm) process model. This work-flow decision was based on the following considerations:

- Speed up completion of the biocomplexity project.
- Facilitate development of the recreation model component by reducing the complexity of the task.
- Allow for the independent development and testing of the recreational component of the model by the recreation research team.

The Swarm model is a complex modeling framework and learning it requires a considerable time investment. In addition, the recreation researchers (including the author) possess limited programming capabilities (and patience). For these and other reasons, NetLogo was chosen as the development platform for the recreational component of the biocomplexity model.

In order to simplify development of the NetLogo recreation template, only a subset of the recreation origins and the recreation sites were considered. The overall strategy was to develop a working and tested recreation template and then integrate it with the larger (working and tested) Swarm based biocomplexity model. The remaining recreation origins and recreation sites would later be incorporated into the Swarm model.

The NetLogo recreation template was designed to simulate the number of recreators across time, their recreation site selection decision and their movements in space and time. Within the larger biocomplexity model, the recreators would interact with the physical and biological resources while present at the recreation sites. Physical representation of these activities within the NetLogo recreation template requires characterizing the recreation origins, a road system and the recreation sites.

Although the use of NetLogo is less demanding than say the use of Swarm, characterization of the origins, a road system, recreation sites and the movement of recreators from those origins to the sites proved to be non-trivial exercise. The NetLogo documentation and code examples contain no pertinent examples of equal complexity. For example, although the NetLogo platform has pre-designed car images which can be associated with movement agents ("turtles", as they are referred to in NetLogo terms), there are no examples illustrating how to move those cars down a road network and keep the cars on the road. As a result, significant impediments were encountered.

Much of the difficult programming work, upon which the NetLogo recreation template is based, was completed by the ever patient and talented Dr. Paul Box, of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Alice Springs, Australia. Dr. Box is a extremely seasoned Swarm modeler. Even so, it required programming skill, ingenuity, experience, perseverance and a tremendous amount of time to craft the NetLogo recreation template.

Figure 1 illustrates the location of each of the recreation sites and the two origins within the NetLogo recreation template. Note that neither the roads nor these locations are geographically referenced within the template and are shown in their approximate locations only. The Rio Mameyes is on the right-hand side of this figure and the Espiritu Santo River is located on the left-hand side. Both rivers flow in a northerly direction (towards the top of the figure) and discharge into the sea.

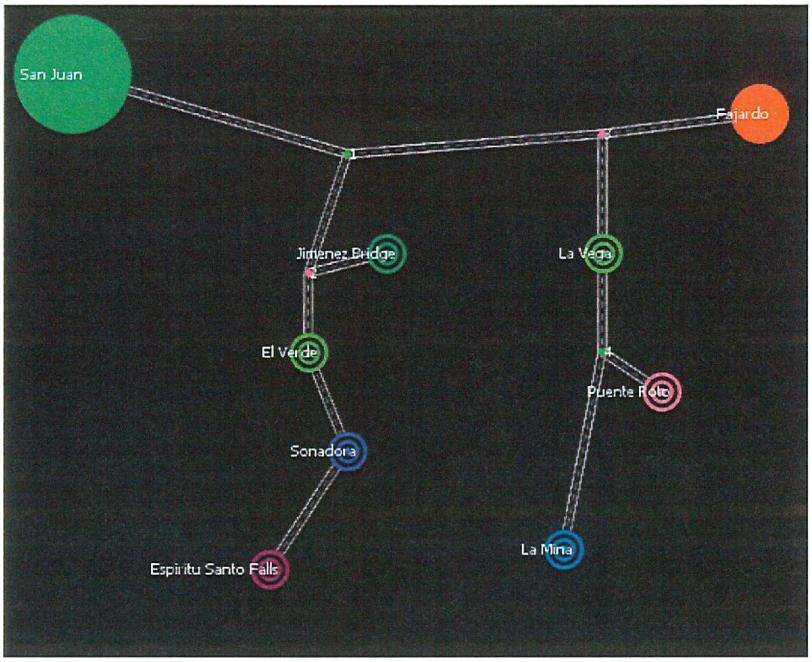

Figure 1. Sites and origins in the NetLogo recreation template

As shown in Figure 1, in the NetLogo recreation template, there are seven possible recreation sites and two origins. The two origins, or towns, are San Juan and Fajardo. The seven recreation sites in the template are La Mina, Puente Roto, La Vega, Espiritu Santo Falls, Sonadora, El Verde and Jimenez Bridge. These recreation sites are listed in upstream to downstream order by river as shown in Table 2 below.

Table 1. NetLogo Recreation Sites By River

Rio Espiritu Santo	Rio Mameyes
Espiritu Santo Falls	La Mina
Sonadora	Puente Roto
El Verde	La Vega
Jimenez Bridge	

Figure 1 and the features described constitute the virtual world characterized in the NetLogo recreation template. Although this world is small and deceptively simple, it is important to note that this synthetic depiction and the rule set described subsequently represent approximately 900 lines of NetLogo code (version PRrec04 dated 6/20/2008).

Recreation, Time and Time-step

The question of model time-step is a critically important consideration in this project. Human beings are highly attuned to the time of the day and their activities reflect this. Furthermore human activities have distinct hourly, daily, weekly, seasonal and annual patterns. In addition, human institutions operate on a time-of-day (clock) basis. For example, recreation sites open at a set time and close at a set time. All of these factors are intimately familiar to suppliers of electricity, who must predict human activities and the consequent electricity demand and supply electricity on a real-time basis.

In contrast, many natural events, such as precipitation, are probably not strongly time-of-day related. Rather, many natural phenomenons are correlated with day length, temperature and other factors. In the natural world, one period may be time indistinguishable from another. Consequently, it may be immaterial whether a particular time-step represents hour 1 on December 2006 or hour 10 on July 4th.

On a purely pragmatic basis, tracking of time and the selection time-step size has a number of implications for this modeling effort. Selection of one year as the time-step may be perfectly reasonable for long-term hydrologic models. However if the goal of the effort is to represent the interaction of shrimp with the physical and aquatic environment, use of an annual time-step may be undesirable. In terms of human activities, let's consider the implications of setting a time-step of 1 day. If we did so, we could readily characterize daily precipitation, stream flow and potentially, movements of shrimp in the river systems. However, selection of a one day time-step would make it impossible to characterize the movement of day-use recreationists from the origins to the site (during a 24hr period, they would have visited the site and returned already). Further, the interaction of these recreators, with the shrimp at specific sites, could not be represented.

As explained, the tracking of time in the model and the choice of time-step has non-trivial implications in this application. For purposes of the NetLogo recreation template, time-of-day is explicitly tracked and a minimum time-step of one hour has been selected.

Recreation Rule Set

The behavior of each of the car agents in the NetLogo recreation template is governed by a simple rule set. A description of each of these rules is provided below.

Recreation Decision

For purposes of the Puerto Rico NetLogo 4.0 river recreation template, the number of recreators departing from each origin and visiting a site somewhere in the study area on a given day is calculated using a simple predictive model.

In the NetLogo template, there are only two possible origins (towns). These are San Juan and Fajardo (n=2).

The number of recreators departing from each of these origins on any given day is predicted by equation (1).

(1) $$nrec_L = b_0 + b_1 * pop_L + b_2 * b_1 * pop_L * we + b_3 * b_1 * pop_L * hol$$

where: $nrec_L$ = number of recreators departing origin (L) in a given day
pop_L = population of origin (L)
we = binary variable indicating the day is a weekend (1=yes, 0=no)
hol = binary variable indicating the day is a holiday (1=yes, 0=no)
L = origin index
b_i = coefficients

In the NetLogo river recreation template, the values of the coefficients are shown in Table 2

Table 2. Coefficients for Recreation Prediction

Coefficient	Value
b_0	1.00
b_1	5.0e-05
b_2	2.00
b_3	14.00

Recent population estimates for each of the (n=2) origins, are shown in Table 3

Table 3. Population By Origin (2008)

Origin	Population
San Juan	2,000,000
Fajardo	40,712

The data employed to predict the number of recreators from each origin are shown in Appendix 1.

Using this approach and the data found in Appendix 2, the number of recreators from each origin in each day are predicted. For purposes of developing and testing the NetLogo recreation template, a single week (7 days) of data were employed. The NetLogo recreation template is designed to simulate recreation for an unlimited number of days. To carry out a longer simulation, the data set shown in Appendix 1 would be replaced by a longer data set using the same format.

Number of Car Agents

The automobile is the most commonly used transportation mode for travel from the origin cities to the recreation sites in the study. The visual component of the NetLogo template is designed to simulate the movement of these recreators in space (from the origin to the destination site) and time. For this reason, cars (agents) were chosen to visually represent the aggregate movement of recreators. To facilitate this in the model, it was assumed that each car was occupied by 2.5 recreators, all going to the same site.

The number of cars leaving each origin on a particular day was calculated by dividing the number of recreators by 2.5.

Site choice

For purposes of the Puerto Rico NetLogo 4.0 river recreation template, the probability of a recreator selecting site (i) for recreation purposes is calculated using a logistic probability function.

The probability of recreator (i) visiting site (j) on a given day is predicted by equation (2).

$$(2) \quad Prob_{i,j} = \frac{1}{1+e^{-(b_0+b_1*TT+b_2*elev+b_3*WF+b_4*P+b_5*AD+b_6*RMD)}}$$

where: $Prob_{i,j}$ = probability of visiting site (i) on any given day
TT = one-way trip travel time from origin (L) to site (i) (minutes)
elev = elevation of the site (i) (meters)
WF = presence of a waterfall at the site (1=yes, 0=no)
P = private land indicator (1=yes, 0=no)
AD = access difficulty rating (units unknown).
RMD=Rio Mameyes indicator (1=yes, 0=no).

L=origin index
i=recreator index
j=site index
b_i = coefficients

In the NetLogo river recreation template, the values of the coefficients in this equation are shown in Table 4:

Table 4. Coefficients for Site Selection Relationship

Coefficient	Value
b_0	0.050
b_1	-0.035
b_2	0.001
b_3	0.001
b_4	-2.500
b_5	-0.500
b_6	0.200

Implementing Site Selection

The site selection approach described above was employed to characterize site choice for each recreator. Review of this approach will reveal that all recreators from site (L) face the same site selection probability. These probabilities are illustrated in Appendix 3. As shown in this appendix, given the current data and site choice equation, the predicted visitation probabilities do not vary, to three decimal points of accuracy, across the origins. This suggests that further attention will need to be devoted to this topic.

Computing these probabilities for each agent from origin (L) would be redundant. For efficiency reasons, these probabilities were calculated externally for each origin and site. These probabilities are coded directly in the NetLogo recreation template and stored as a set. Each car agent in the simulation is randomly assigned to travel to a specific recreation site based on the probability that a recreator from origin (L) would visit site (J).

Departure time

When an individual has made the decision to recreate and has selected a site to recreate, they are faced with a decision about when to depart the origin for recreation site.

As implemented in the NetLogo recreation template, an agent's departure time was determined by selecting a uniformly and randomly selected time between the time the gates open at the National Forest (0600 hours) and 1400 hours.

Desired Onsite time

The time an individual spends on-site at the recreation location can be quite variable. It depends on personal preferences, weather, season, length of day, the preferences of their traveling companions, other time constraints and the administratively determined times when recreation is permitted.

As implemented in the NetLogo recreation template, an agent's onsite time was determined by a very simple rule. All agents were uniformly and randomly assigned an onsite time between 2 and 7 hours. This onsite time was conditioned on the return time required to achieve a departure from the National Forest prior to the time the gates close (1900 hours).

Return time

An individual's decision about when to start their return from the recreation site to their origin was represented using simple rule set. An individual's return time was assigned to be the sum of their start time and their onsite time. Their return time was then compared to the time when the gates of the National Forest close (1900 hours). If the return time exceeded the time the gates closed, the return time was adjusted downward to allow the recreator to exit before the park was closed.

Parking Constraints

The current version of the NetLogo recreation template does not include any consideration of parking constraints. As currently coded in the model, each of the car agents journey to the recreation sites and park there, without regard to the number of other cars currently at the site.

Santiago, Gonzalez-Caban and Loomis (2008) visited each of the recreation sites depicted in the template and have identified the maximum number of vehicle parking places at each site. The parking capacity at each site in the template is shown in Table 5.

Table 5. Maximum Parking at Each Recreation Site

Recreation Site	Maximum Parking
Espiritu Santo Falls	30
Sonadora	50
El Verde	25
Jimenez Bridge	30
La Mina	60
Puente Roto	150
La Vega	100

As shown in Table 5, several of the recreation sites have significant parking capacity. For example, La Vega has a parking capacity of 100 vehicles. Assuming that each vehicle contained 2.5 persons, this implies that, at capacity, 250 people could be recreating at the site at any one point in time.

Under ordinary circumstances, the parking capacities shown in Table 5 do not constrain recreation. During periods of peak use, such as holidays, the available parking capacity does limit the number of recreators who can use a particular site. If recreators are unable to find parking at their intended recreation site, they are likely to divert to another nearby presumably less attractive site that has available parking.

The current version of the NetLogo recreation template does not include any rules to simulate the behavior of recreators when parking constraints have been reached.

FS Use Constraints

The current version of the NetLogo recreation template does not include any consideration of Forest Service recreation use constraints. As currently coded in the model, each of the car agents journey to the recreation sites and park there, without regard to the number of other cars currently at the site.

To avoid excessive use and prevent resource damage, the Forest Service (FS) limits use of the recreation sites on the Rio Mameyes. On certain holiday weekends, FS staff man traffic control gates along the road and preclude entry after a specified number of vehicles have entered.

Vehicles stopped at these gates form a queue at the gate until another vehicle has left and they are admitted, travel to another recreation site outside of the National Forest, or they lose patience and return home.

The current version of the NetLogo recreation template does not represent the behavior of recreators when FS recreation use constraints have been reached.

Running the NetLogo ABM Model

Figure 2 shows the NetLogo recreation template as it appears inside the NetLogo Version 4 program. Operation of the program requires the user to execute a 3 step process in a specific order. First, click on the "Clear-all" button located on the upper left-hand corner of the visual user interface. This will clear the interface so that a blank screen or world is shown. More importantly, it will reset NetLogo, deallocating all existing data structures and variables. Next, click on the "Setup-world" button. This will assign values to the global variables, construct the virtual world and load the test input data file. A user dialog will appear reporting that the input file has been read. Click, "OK" to continue. Finally, click on the button labeled, "Run-simulation." This will initiate the simulation run.

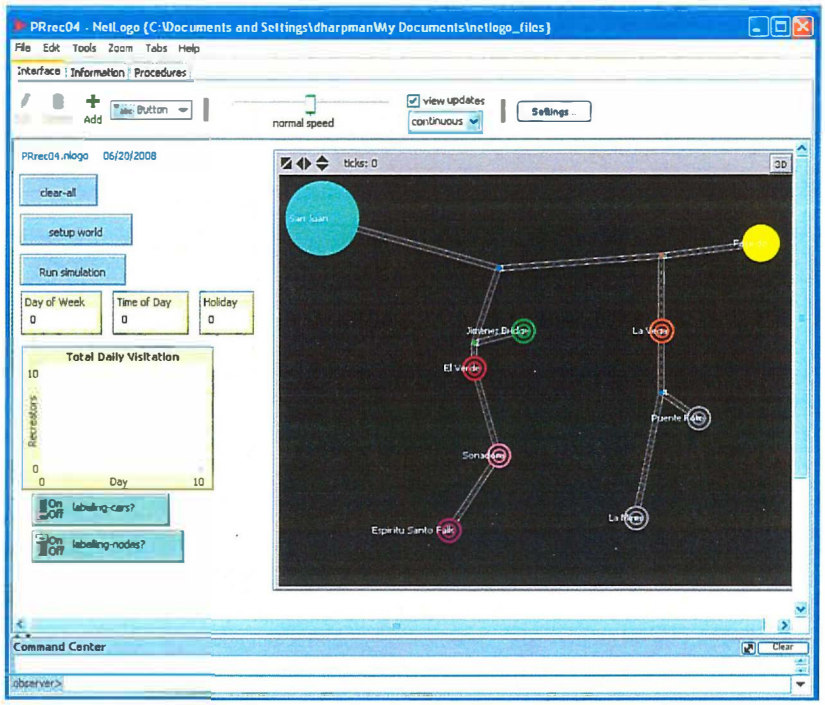

Figure 2. Recreation template in NetLogo 4

As can be monitored by watching the day of week and time of day reporters, the simulation starts on Saturday at 0000 hours. It proceeds forward hour by hour. Note that for the test input data set, Monday is a holiday. As a result a relatively

large number of recreators are created on Monday and the simulation will take noticeably longer relative to other days in the data set.

For each day in the simulation, some vehicles will begin leaving their respective origins at approximately 0600 and driving towards their recreation destinations. The number of recreators leaving a given destination and the time of their departures are governed by the rule set described previously. When the recreators arrive at their destination sites, they stop there and recreate. The car agents remain at their recreation site for a period of time determined by the on-site time rule. When their departure time is triggered, the car agents drive back to their respective origins along the road network.

To the observer, car agents will leave their origins, drive along the road network to their choice of recreation site, recreate at the site and then drive back to their origins. During the daylight hours of a simulation, a subset of car agents will be driving to their destinations, some car agents will be recreating and other car agents will be returning to their origins. All of these actions will appear to be occurring concurrently, as it does in the real world.

Advantages of ABM

The use of ABMs in recreation economic analysis seems to hold considerable promise. The behavior of individual agents in an ABM is governed by simple rules allowing for a tremendous amount of flexibility in the range of activities that can be characterized. Relative to other approaches and even traditional simulation models, ABMs allow for the spatial nature of the recreation space to be portrayed. The movements of agents within this space can be time-referenced. In these respects, ABMs are a unique and extraordinarily powerful modeling innovation.

The use of ABM models can capture unforeseen and unpredicted recreation behaviors. These emergent properties are the hallmark of ABM applications. To the extent that emergent properties occur in a simulation, they can provide insights beyond those of many existing approaches.

Finally, a notable strength of ABM models is their suitability for investigating the effects of new recreation sites. ABM models, which are based on simple rules, can allow for the prediction of recreation use and economic value at hypothetical recreation sites which are introduced into an existing model. By observing the behavior of individual agents who have been presented with an increased recreation site choice set, they can characterize the extent of site substitution, an acknowledged weakness of more traditional recreation analyses.

Disadvantages of ABM

The programming tools currently available for developing ABMs are crude by comparison with well-developed programming environments such as Borland Studio © and Microsoft Visual Studio ©. Higher level languages for ABM development are object based, but the documentation for these objects, which most programmers rely on, is either non-existent or incomplete. As a result, construction of even relatively simple ABMs is an onerous, tedious and time-consuming process.

Conclusions

This document introduces agent based models, their history, underpinnings and the mechanics of their application. The spectrum of previous ABM applications has been summarized and a number of recreation ABM efforts have been reviewed. Some of the existing tools for ABM analysis have been documented and the deployment and use of the NetLogo ABM platform has been described in some detail. A NetLogo recreation application has been developed in collaboration with researchers engaged in an ongoing NSF project based on ABM. This example application is designed to allow readers to understand and apply the methodology. The ABM application simulates water-based recreation in Northeastern Puerto Rico. The construction of the recreation rule-set used in this application, including the conceptual and mathematical details of this application is detailed.

The use of recreation ABMs to estimate the use and value of planned recreation sites holds considerable promise. Individual recreation agents are endowed with general but simple rules which govern their decision to recreate and their selection of a recreation site to visit. These flexible rules allow ABMs to simulate recreation not only at existing sites but at new or nonexistent recreation sites.

ABMs can facilitate insights about the evolution of complex systems and possible macro/aggregate outcomes based on the interaction of different classes of individuals with each other and their environment. ABMs and their application to recreation are "state-of-the-art" innovations in recreation and recreation economics. Many future applications of this rapidly evolving methodology are expected. These applications will be facilitated by the development of new, more specialized and easier to use ABM tools. It is hoped this manual will provide economists, environmental scientists and policy makers some conceptual and technical insight into this evolving modeling approach.

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Appendix 1. Test Input Data Set

For purposes of testing the algorithm which characterizes the recreation decision, as well as constructing and testing the Netlogo recreation template, the test input data set illustrated in Table 6 was employed.

Table 6. Test Input Data Set

Day of Week	Weekend	Holiday
Sunday	1	0
Monday	0	1
Tuesday	0	0
Wednesday	0	0
Thursday	0	0
Friday	0	0
Saturday	1	0

As shown, the current data set is only 7 days in length. These data were used for testing and development of the NetLogo recreation template. The NetLogo template has been designed to use a data set of arbitrary length. Longer simulations of a user defined length can be undertaken by constructing and using an alternative input data set, encompassing the desired simulation period, which employs a format identical to the one shown in Table 6.

Appendix 2. Recreation Site Data

The data used in the site selection rules for each site (j) are shown in Table 7.

Table 7. Recreation Site Data

Site	TT-SJ	TT-F	Elev	WF	P	AD	RMD
Espiritu Santo Falls	37	29	364	1	0	1.50	0
Sonadora	35	27	291	1	0	2.00	0
El Verde	33	25	50	0	1	-1.60	0
Jimenez Bridge	30	22	17	0	1	-1.20	0
La Mina	44	31	498	1	0	0.72	1
Puente Roto	39	26	90	0	0	0.90	1
La Vega	33	20	20	0	1	-1.75	1

where: $Prob_{i,j}$ = probability of visiting site (i) on any given day
TT-SJ = one-way trip travel time from San Juan (minutes)
TT-F= one-way trip travel time from Fajardo (minutes)
elev = elevation of site (i) (meters)
WF = presence of a waterfall at the site (1=yes, 0=no)
P = private land indicator (1=yes, 0=no)
AD = access difficulty rating (units unknown).
RMD=Rio Mameyes indicator (1=yes, 0=no).
L=origin index

These data were provided by Dr. Luis E. Santiago, Graduate School of Planning, at the University of Puerto Rico. Dr. Santiago is a co-principal investigator on biocomplexity project and the lead author of Santiago, Gonzalez-Caban and Loomis (2008). These data were collected by Luis Villanueva, Masters Student in the Graduate School of Public Planning, University of Puerto Rico and by Andrew Pike, currently with the National Marine Fisheries Service.

Appendix 3. Site Choice Probability

This appendix further describes the probability that an individual from a given origin will select a site (j) for recreation on a particular day.

As described in the text, the probability of recreator (i) visiting site (j) on a given day is predicted by equation (2). The values of the parameters used in equation (2) are shown in Table 2. Applying this equation with the parameters described, the probability that an individual from San Juan or Fajardo will recreate at one of the seven recreation sites in the template is shown in Table 8 below.

Table 8. Probability of Site Selection By Origin

Site	From San Juan	From Fajardo
Espiritu Santo Falls	0.180	0.167
Sonadora	0.145	0.136
El Verde	0.066	0.063
Jimenez Bridge	0.058	0.056
La Mina	0.264	0.270
Puente Roto	0.205	0.215
La Vega	0.083	0.092
see filename=Rev RM&ES Probs 7-21-08.xls		

As shown in Table 8, use of this approach and these coefficient values provides some rather plausible results. Recall that Fajardo is closer to the recreation sites on the Rio Mameyes (La Mina, Puente Roto and La Vega) and San Juan is closer to the recreation sites on the Rio Espiritu Santo (Espiritu Santo Falls, Sonadora, El Verde and Jimenez Bridge). Then note that these probabilities are consistent with the available evidence and the pattern of observed visitation.