From: http://photos.turksandcaicostourism.com/nature/images/tctb_horz_033.jpg

Use of Agent Based Modeling in an Ecological Conservation Context

Scott B. WOLCOTT[1]*, Michael E. LONG[2]

[1]Department of Civil Engineering Technology, Environmental Management & Safety, Rochester Institute of Technology, Rochester, NY

[2]CFC Center for Imaging Science, Rochester Institute of Technology, Rochester, NY

***Corresponding author e-mail** *sbwite@rit.edu*

Keywords: Agent based modeling, ABM, iguana, conservation, ecological

Cyclura carinata carinata, a rock iguana native to the Turks and Caicos Islands, is categorized as critically endangered on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Habitat loss and invasive *predators have decimated the population of Cyclura carinata and reduced their range to a few small islands. Conservation efforts have been successful in reintroducing the iguanas to portions of its historical range after non-native predators (mostly cats) have been eliminated. This contribution uses agent-based modeling (ABM) to simulate the life cycle of rock iguanas in a natural setting without invasive predators. Life as characterized by eating, moving, resting, mating, oviposition, hatching, and death by starvation, old age, natural predation are modeled as well as new plant growth and the spreading of plants. These conditions are modeled under two scenarios: 1) evenly age distributed iguanas randomly distributed across an "island" and 2) adult iguanas introduced to an "island" at a single location. Iguana population growth and edible plant growth are modeled to determine sustainable food to iguana ratio. Results indicate similar sustainable plant to iguana ratios of 5.5:1 for each starting scenario.*

Introduction

Turks and Caicos rock iguanas. The Turks and Caicos rock iguana (Cyclura carinata carinata) is a relatively small rock iguana (see Fig. 1). Males reach a snout to vent length (SVL) of 36.0 cm and weigh up to 1.86 kg. Females are smaller, weighing as much as 1.14 kg with a SVL of 29.0 cm (page 17, Lemm and Alberts, 2012).

Fig. 1. *Female Turks and Caicos rock iguana with tagging beads. From: http://www.wherewhenhow.com/turks-caicos-islands/uninhabited-caicos-cays/*

The rock iguanas are primarily herbivores that typically feed on the young leaves and sprouts of over 50 plant species. When available, the rock iguanas will also feed on the flowers and fruits of the same plant species. While plants account for approximately 95 percent of the iguanas' diet, they will eat insects and carrion if the opportunity presents itself (Iverson 1979).

Turks and Caicos rock iguanas reach sexual maturity between 6 and 7 years and mate in late April to early May. Males will continue to seek females after mating, while the females will not seek males. Females build nest burrows and lay between 2 to 9 eggs in early June. The eggs hatch 80-90 days later and the hatchlings immediately disperse.

Rock iguanas are long lived in the absence of introduced predators, such as dogs and cats. Many are thought to live to 20 years and perhaps as long as 25 years (Iverson, 2012). Adult iguanas (i.e. greater than 6 years old) are too large for natural predators. Hatchlings and small juveniles can fall prey to natural predators such as birds and snakes.

The iguanas currently inhabit approximately 50 of the over 200 islands, or cays, that make up the Turks and Caicos island banks. These flat limestone islands with rocky coppice and sandy vegetated strands represent 5 percent of what is thought to be the original range of the Turks and Caicos rock iguana (page 18, Lemm and Alberts, 2012). Although, Cyclura carinata carinata is considered to be the most populous of West Indies rock iguanas with a population of approximately 50,000, it has been added to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species as critically endangered (Fig. 2).

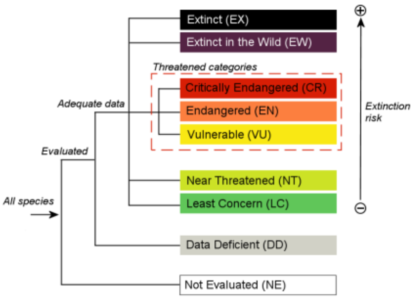


Fig. 2. *IUCN Red List Categories (From: http://www.iucnredlist.org/about)*

Feral dogs and cats are the primary reason for the sharp decline in rock iguana populations. Nearly 15,000 iguanas were killed by dogs and cats brought by construction workers in the 1970s (page 20, Lemm & Alberts, 2012). In addition to introducing predators, development of islands in the Turks and Caicos archipelago has reduced suitable habitat and has caused many iguana road kill deaths.

In an effort to save the Turks and Caicos rock iguana from extinction, scientists have translocated adult iguana to islands without invasive predators and low probability of development. Government officials have also developed protective policies for islands with existing populations of iguanas and commercial and residential developments.

Agent Based Modeling (ABM)

Agent based modeling is a relatively new concept. Its origins can be traced to the 1940s, but ABM began to expand in the 1970s and 1980s as computers became more powerful and accessible. Traditional models consist of equations and algorithms that describe a system's output based on the input parameters. The equations in these models have been developed and calibrated based on various input parameters at a system-level scale. Consequently, the system performance and outcome has been predetermined.

ABM is often referred to as a bottom up modeling process because the system outcome is a result of how the individual components (or agents) in the system react to each other and environmental factors. In ABM, individual, heterogeneous agents are all given a set of rules to follow. The agents interact with each other and their environment based on these rules. The emergent behavior and system outcome of AMBs are the result of the cumulative outcomes of individuals in the system (Long, n.d.). Macy and Willer (2002) identified four key assumptions of ABMs, as follows:

1. *Agents interact with little or no central authority or direction*. Global patterns emerge from the bottom up, determined not by a centralized authority but by local interactions among autonomous decision-makers. This process is known as "self-organization".
2. *Agents are interdependent*. All ABMs assume that agents influence others (directly or indirectly) in response to influence that they receive.
3. *Agents follow simple rules*. Although the rules may be quite simple, they can produce global patterns that may not be at all obvious and are very difficult to understand. ABMs are designed to explore the minimal conditions, the simplest set of assumptions about behavior, required for a given phenomenon to emerge at a higher level of organization.
4. *Agents are adaptive and backward-looking*. In other words, the agents learn as the model proceeds. Not all ABMs incorporate learning. Similarly, this assumption has not been applied to the subject of this paper. It is assumed that agents inherit their traits and do not learn.

ABMs consist of computational components called “patches” and “turtles”. Patches are the environment where the turtles live. Turtles can move but are not required to do so, while patches are static. There can be several different types of patches and turtles. Each type of patch and turtle has group characteristics and rules. The magnitude of the characteristics can change for individual turtles as they react with their environment and other turtles. In this study, patches represent the island and the sea around it. Iguanas, edible plants, eggs, and a predatory bird are all different breeds of turtles in the ABM context.

Method

NetLogo 5.0.1 (Wilensky, 1999), released in April 2012, was used for modeling iguanas under the two scenarios in this paper. The setting is an island, which is represented by patches colored yellow for sand and cyan for the sea.

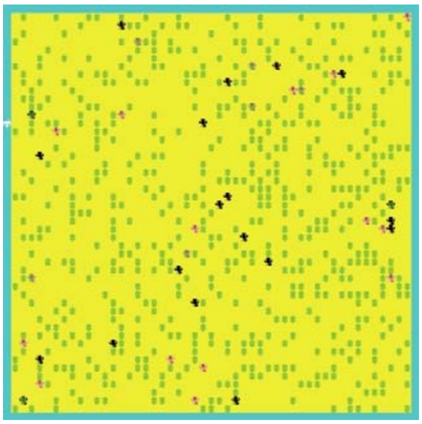


Fig. 3. *Scenario 1: Distributed population*

Two scenarios were selected as starting points for modeling iguanas. The first scenario assumes that the island is populated with a specified number of female (FIGGYS) and male (MIGGYS) iguanas randomly distributed throughout the island. The iguanas are of randomly distributed ages between 4 months and a life expectancy of all iguanas (Fig. 3). The second scenario assumes that an equal number of FIGGYS and MIGGYS are reintroduced to a specific location on the island (Fig. 4). Only adult iguanas over the age of 6 years are used in translocation programs. Evidently, the determination of the exact age of adult iguanas is difficult and actual ages are not specified. Therefore, the age of the reintroduced iguanas in the scenario are randomly distributed between 6 years and 4 months to the life expectancy. The 4 month period in each scenario exists because iguanas hatch in late August to early September.

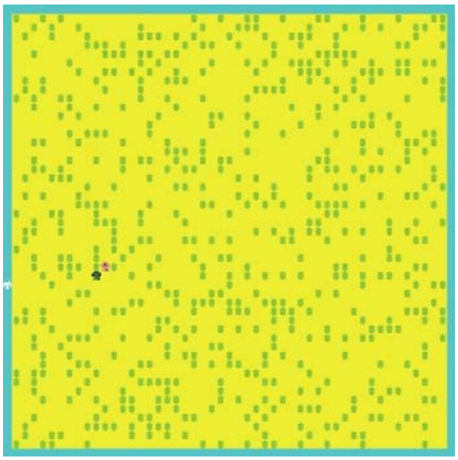
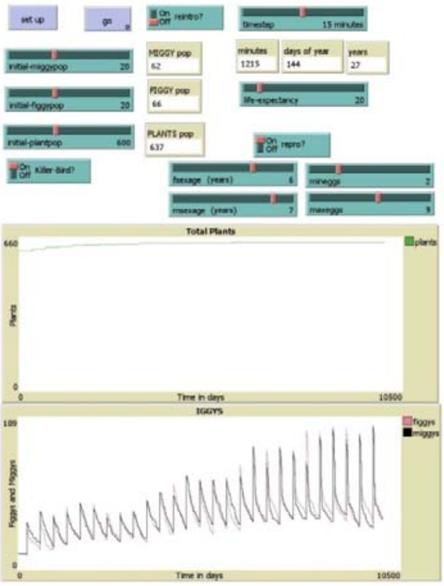


Fig. 4. *Scenario 2: Reintroduction*

There are four turtle breeds in the model: plants, FIGGYS, MIGGYS, and the predatory bird. Many of the initial settings for the turtle breeds can be set on the model interface (Figure 5). The initial number of plants, FIGGYS, and MIGGYS can be established. The age of sexual maturation for FIGGYS and MIGGYS, the minimum and maximum number of eggs in each clutch and life-expectancy can be selected at the interface using sliders. Scenario selection, reproduction routines, and predation can be turned on using on/off switches. Finally, the time step can be selected within a range of 5 to 30 minutes.



reintro? Off

timestep 15 minutes

initial-miggypop 20

MIGGY pop 62

minutes 1215

days of year 144

years 27

initial-figgypop 20

FIGGY pop 66

life-expectancy 20

initial-plantpop 600

PLANTS pop 637

repro? On

Killer-Bird? On

fsexage (years) 6

mineggs 2

msexage (years) 7

maxeggs 9

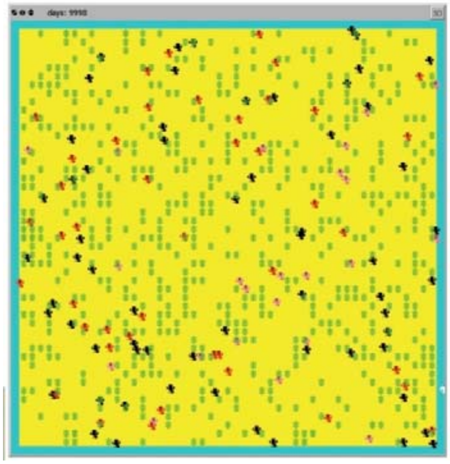


Fig. 5. *Interface for IGGY v2.0*

In NetLogo, commands are executed at each “tick”. The time step selected at the model interface provides a temporal scale to the computational tick. The time of the day, day of the year, and years can be determined based on the time step selected. A correction factor was added to the model to correct for time steps less or greater than the median of 15 minutes. This corrected energy gains and losses associated with moving, eating, mating, and laying eggs that would occur. For example, if a time step of 5 minutes were selected, each iguana would execute six actions compared to a single action under a 30-minute time step. The advantage of a larger time step is computational speed, however the cost is sacrifice of accuracy. A smaller time step allows the iguanas to move a greater distance during each day. In turn, the additional moves provide an iguana with greater opportunity to find food and mates. A consequence of additional moves is increased opportunity for predation of juvenile iguanas.

Initial settings and simple rules for the four turtle breeds in the model: plants, FIGGYS, MIGGYS, and the predatory bird are explained in the following paragraphs.

PLANTS: All plants are considered to be edible, but only if they have a specified energy level. The initial plant population has a randomly distributed energy level between 50 and 100. Plants having an energy level above 50 are considered to have something available (young leaves, sprouts, flowers or fruits) for the iguanas to eat. If an iguana is at the same location as a plant, the plant loses energy (1). The minimum amount of energy for a plant is 50. Iguanas do not kill plants by over browsing, but they can reduce its reproductive capability.

If a plant has an energy level at or above 100 at the beginning of the year, it duplicates itself. Both the parent and child plant have new starting energy levels of 50. This rule assumes that the parent plant has lost all edible portions by “fruiting” and the child plant is too small to provide energy to the iguanas. Plants add one unit of energy each day.

FIGGYS and MIGGYS: Female and male iguanas are similar except in reproduction roles. The initial population of females and males are set at the interface. The energy level is randomly set between 50 and 100. If the energy level of an iguana falls to or below zero, it dies. The metabolism of each iguana is randomly set between 0.1 and 0.12. Iguanas use energy at its metabolic rate at each time step. The iguanas are only active between the hours of 0945 and 1545. The iguanas only use 1 percent of their metabolic rate when inactive.

Iguanas in the model have varying levels of vision of 1 to 4 patches. This allows them to "see" edible plants in a 360° circle of vision patches. An iguana will move towards an edible plant if the plant has energy of 70 or above. If an iguana is on the same patch as a plant with energy greater than 50, the iguana adds 5 units of energy. Iguanas can eat continuously if they are on plants with energy greater than 50. There is no maximum energy for the iguanas. However, if the energy of an iguana falls to zero, it dies.

Vision also helps the male and female iguanas find the opposite sex during mating season which is modeled between April 24 and May 7. Adult (age $\geq$ 6 years) female and male iguanas move towards each other during mating if they can see an adult member of the opposite sex within its vision.

If an adult male and female iguana occupies the same patch during mating season – they copulate and the female becomes pregnant. Female iguanas will stop seeking males after they become pregnant. In the model, they turn from pink to red color. Males continue to seek females for the entire mating season. This reflects reality, Iverson (1979) reports that females are not receptive to mating after they become pregnant, but males continue to pursue female iguanas regardless if they are pregnant. During the first week of June, pregnant females lay a clutch of eggs if they are at a patch occupied by a plant. The process of laying eggs reduces the female's energy by 5. After the females lays eggs, its color changes back to pink color. The plant acts as a nesting burrow in this model. No new nesting burrows are dug.

The number of eggs in a clutch is randomly selected between the minimum and maximum number of eggs in a clutch, which is set at the interface. The minimum and maximum eggs per clutch used in this study are two and nine, respectively (Iverson, 1979). The eggs all hatch on August 31 with initial energy of 100 (yolk sac), metabolism, vision, and age of zero. The number of males and females hatched is random and equally distributed. Hatchlings begin seeking edible plants immediately and are modeled with rules similar to all iguanas with the exception of seeking mates. They begin to seek mates when they reach sexual maturity. Sexual maturity for female and male iguanas can be varied in the model between two and eight years.

PREDATORY BIRD: The use of a predator can be selected at the interface. In this case, a bird flies over the island seeking iguanas 2years old and younger. The bird can see its patch and patches ahead in a cone of 90°. The vision range is set in the code. The bird is allowed to catch iguanas only during the active period and when the iguana is not occupying the same patch as a plant (i.e. hiding). The bird is allowed to only catch one iguana per day. If the bird does not see an iguana, it travels in a random direction 3 patches per time step.

Results

Several modeling runs were completed during this study. The first scenario compared an established population vs. reintroduction. The initial parameters for each run were as follows:

- 15 minute time step;
- 20/20 female/male iguanas; and
- 600 edible plants.

The findings of this simulation indicate that a dispersed population of all ages vs. a centralized reintroduced population of adults has little if any impact on the iguana and plant populations 20 years later. Fig. 6 shows the trends in plant and iguana populations through a 25 year period. Stable plant and iguana populations are maintained after 20 years. The ratio of plants to iguanas is on average 5.5:1.

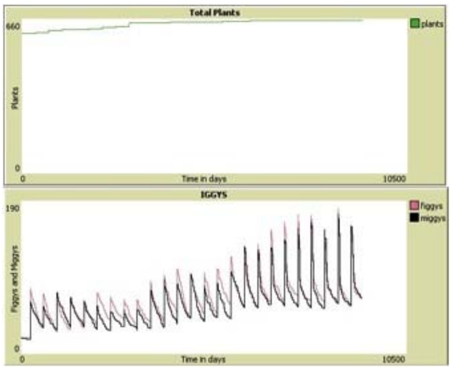


Fig. 6. *Population trends over a 25-year period of initial population vs. reintroduction.*

More extreme initial conditions were also investigated. In one case, the initial population of plants was reduced to 200 while the initial population of male and female iguanas was 20 each. Fig. 7 presents the population trends in this case. It shows that there is an increase in plant population that corresponds with a decrease in the iguana population. The populations seem to be stabilizing after 27 years with a plant to iguana ratio of 6:1. Two additional runs were modeled under the same conditions and resulted in earlier stabilization and ratios of 4:1 and 5.7:1. These modeling runs indicate that a plant to iguana ratio of approximately 5.5:1 will be attained under a reasonable range of initial conditions.

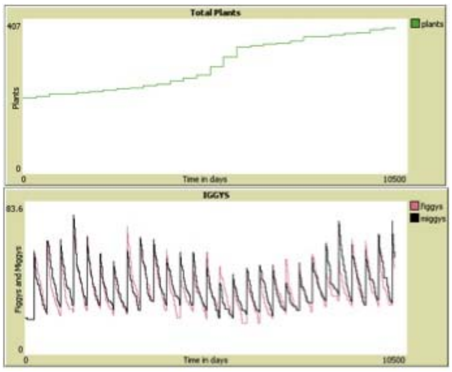


Fig. 7. *Population trends over a 25 year period with reduced plants.*

Additional runs were performed with increasing populations of iguanas while reducing the initial population of plants. An interesting pattern emerged. As expected, the iguana population crashes in the first year. Depending on the number of initial iguanas, one of three outcomes occur: 1) All iguanas die off in the first two years if there are not enough plants; 2) a few iguanas survive, but the breeding is intermittent and hatchlings usually die. Eventually the iguana colony dies of old age; 3) the population of iguanas slowly recovers and a stable population results as the plant population increases exponentially (Fig. 8). The plant population increases, but because the initial population is low, the new growth is localized resulting in dense growth at isolated locations (Fig. 9). This results in iguanas having to move farther to find plants with energy above 70. More movement without eating, results in less energy for the iguanas and more predation of juveniles as they move between "groves".

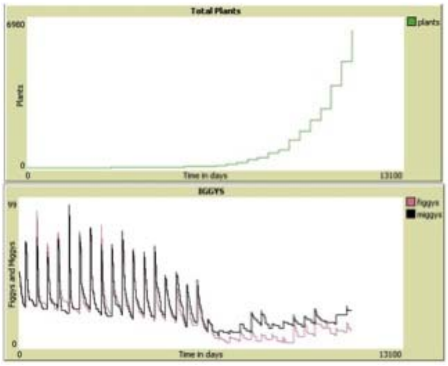


Fig.8. *Low but recovering iguana populations and increasing plant populations.*

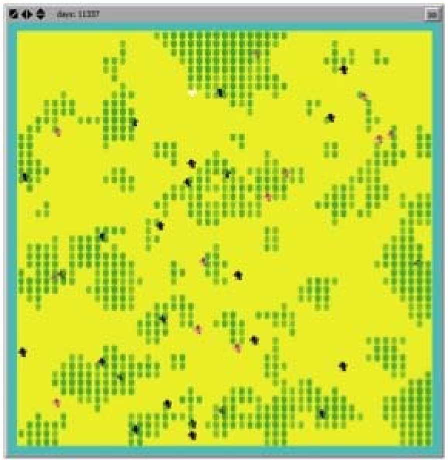


Fig. 9. *Groves of plants with stable iguana populations and increasing plant populations*.

The final extreme scenario involved low initial populations of iguanas (20 total) and large initial populations of plants (900). The iguanas live well under these conditions, with many hatchlings surviving to adulthood (Figs. 10 and 11) because there is abundant food and shelter from the predatory bird. The population of iguanas increases 500% in 10 years. The plant to iguana ratio for initial conditions, at 5 years, and at 10 years were 45:1, 20:1, and 15:1, respectively. This suggests a trend towards a stable 5.5:1 ratio.

Summary and Recommendations

The life cycle Turks and Caicos rock iguanas have been successfully simulated using an agent-based model. A plant to iguana ratio of 5.5:1 appears to be the sustainable mix of food to consumers in this computer model environment. Models with initial plant to iguana ratios as high as 45:1, resulted in increased iguana populations because of abundance of food and moved towards a ratio of 5.5:1. Initial plant to iguana ratios, as low as 0.5:1, produced stable iguana populations, but in a much different landscape. Plant population growth accelerates as the initial population of iguanas crashes to a low, but sustainable level. However, the plants grow in isolated dense groves. This arrangement, rather than a dispersed plant populations does not appear to support as many iguanas. This is the result of additional movement required to reach visible edible plants and less safe cover for young iguanas who fall prey to the predatory bird.

The quantitative results of the model are based on many factors, including the energy levels of plants and iguanas and associated metabolic rates. Energy use and storage is an area of uncertainty in the model and because of this, values such as the 5.5:1 plant to iguana ratio should be considered conceptually sound, but potentially inaccurate. Future models should incorporate more refined data on energy use by both plants and iguanas. Other recommendations for improvement or expansion of this model include:

- Add routine for female iguanas to dig nesting burrow and protect it for one week following oviposition;
- Randomly distribute the life expectancy around a mean;
- Incorporate GIS of islands and edible plant locations; and
- Correlation of appropriate time-step to field data of iguana activity.

References

Gerber, G. 2004. *Cyclura carinata*. In: IUCN 2012. IUCN Red List of Threatened Species. Version 2012.1. <www.iucnredlist.org>. Downloaded on 14 August 2012.

Inverson, J. P. (1979). Behavior and ecology of the rock iguana: Cyclura carinata. Bulletin of the Florida state museum biological sciences. Volume 24. Number 3.

Kaufman, S. (1996). At Home in the Universe: The Search for the Laws of Self-Organization and Complexity. Oxford: Oxford University Press.

Lemm, J. A., Alberts, A. C. (2012). Cyclura: Natural history, husbandry, and conservation of west indian rock iguana. London, England: Academic Press.

Long, M. E. (n.d.) Retrieved from http://people.rit.edu/~melsch/index.html.

Macy, M. W. and Willer, R. (2002). From factors to actors: Computational Sociology and Agent-Based Modeling. Annual Review of Sociology, 28, 143-166.

Wilensky, U. (1999) NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL