At Loggerheads: Modeling the Impact of Temperature on Turtles

Project Module Associated with
2nd Edition, Introduction to Computational Science:
***Modeling and Simulation* by**
Angela B. Shiflet and George W. Shiflet
Wofford College

Prerequisite: *Module 11.2, "Agents of Interaction: Steering a Dangerous Course"*

Introduction

Sea turtles, now found in most temperate and warm ocean waters, have existed for more than a hundred million years. However, almost all species of these creatures are now threatened by a variety of human activities—bycatch of fishing, loss of nesting habitat from development, contamination of sea water by pesticides and other chemicals, plastic, etc. More than ever, it is important for scientists to understand what factors influence their reproduction, development, and survival.

After mating, female sea turtles temporarily leave the ocean for sandy shores to dig nests, deposit their shelled eggs (50-150 eggs), and cover the nest (Miller, 1997). Inside their nest, the young develop until they mature sufficiently to break out of the shell and dig their way to the surface. The miniature hatchlings then must make a mad dash to the sea, trying to avoid a horde of predators along their way. Even when safely adrift in coastal waters, they face a path fraught with predators and other perils to the open ocean, where they feed and grow for many years into sexually reproducing adults.

While in the nest, one of the most important factors influencing the development of the young is nest temperature. Temperature influences the rate of development, size, physical motility of hatchlings, which of course, influences the survival of the hatchlings.

One of the more interesting influences of temperature is sex determination and the consequent sex ratio of the hatchlings. Turtles, like many other reptiles, have their sex determined by developmental temperatures. Mammals and many other animals appear to have their sex determined by genetic information (GSD—genetic sex determination), but turtles' sex is governed by temperature, an environmental factor (ESD—environmental sex determination). Sea turtle species display characteristic **pivotal temperatures**, which are the incubation temperatures at which the number of female and male hatchlings will be equal (Mrosovsky and Pieau 1991). According to Mrosovsky (1994), the pivotal temperature (PT) for most species fell into the 29.0 to 30.0° C range. As incubation temperatures increase from the PT, the proportion of females increased; and as they decreased from the PT, a higher proportion of males were produced (Wibbels 2003). In this module, we will model the impact of temperature on turtle populations.

Projects

For the projects, consider the following data on sea turtles:

- Loggerhead sea turtles nest between mid-March and late September.
- Peak nesting occurs in June and July.
- The breeding interval is usually twice as long for females as males (Hays et al. 2017). After a laying year, mature females do not lay eggs for two or three years. However, mature males can mate every year (Wikipedia 2018).
- Jensen et al. gives a clutch's size as about 100 eggs (2018). Another source for green sea turtles indicates a variation in clutch size, depending on the age of the mother, of from 85 to 200 eggs (Wikipedia Green 2018).
- A sea turtle female lays several clutches in a season (Jensen et al. 2018). Female loggerhead sea turtles lay about four egg clutches in a laying year (Wikipedia Loggerhead 2018). Because a female can store sperm, one male can fertilize multiple clutches (Laloë et al. 2016).
- The incubation period for a sea turtles is about 55 days (Jensen et al. 2018).
- As the incubation temperature increases, the chance that a healthy turtle will hatch decreases. The hatchling success probability has been modeled as $0.89 / (1 + e^{(1.20(x - 32.6))})$, where x is the incubation temperature in °C (Hays et al. 2017).
- Temperature determines the sex of a sea turtle, with warmer temperatures resulting in fewer males. The probability of the hatchling being male has been modeled as $1 / (1 + e^{(1.30(x - 29.1))})$, where x is the incubation temperature approximately midway through the incubation time in °C (Hays et al. 2017).
- The mean temperature of the nest is typically warmer and less subject to fluctuation than the mean temperature of the air. One study estimated that the mean daily nest temperature was 4.44 plus 0.962 times the mean daily air temperature (Godley et al. 2001).
- Loggerhead sea turtles have 11% annual mortality rate (Tomaszewicz 2015).
- On a typical nesting beach, the average air temperature might be 16 °C in December-January and 28 °C in June-July.
- Loggerhead turtles mature in 17-33 years (Wikipedia Loggerhead 2018).
- Their life span is 47-67 years (Wikipedia Loggerhead 2018).

Using these data, determine the pivotal temperatures for hatchling success and sex ratio. For each of the following situations, develop an agent-based simulation, displaying plots of the number of animals and the percent of males at each time step. Possible inputs are the initial number of animals, the initial percent of males, and temperature change from the normal temperatures (°C). Other possible outputs are the average number of mature animals, the maximum age, and the time. Be sure to use a consistent time step, such as month or day. After development, run appropriate simulations for 50 years and discuss the impacts of warmer temperatures, the initial number of animals, and the initial percent of males.

1. Consider sea turtles assuming a constant temperature, a set clutch size with one clutch per year, and a fixed maturity age.

2. Consider sea turtles assuming a constant temperature and a fixed maturity age.

3. Consider sea turtles assuming a constant temperature.

4. Consider sea turtles, where the temperature varies appropriately throughout the year.

5. For one of the above situations, develop a program that runs the simulation a given number of times. The program should display the average final number of mature turtles; in appropriate cases, the time to extinction; and, in the cases where extinction does not occur, the average final percent males or the average percent males during the last year.

6. Employing (Lang and Andrews 1994) and other references, as needed, develop an agent-based model for the American alligator (*Alligator mississippiensis*).

7. Employing (Lang and Andrews 1994) and other references, as needed, develop an agent-based model for the Indian mugger crocodile (*Crocodylus palustris*).

References

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