BIOU9PC: Population and Community Ecology

Lab Practical Week 5 & 6: Decision making for sustainable management using stochastic population models

10 & 17 October 2016

**Objective**

The aim of this two-week-long practical are:

1. To understand why stochasticity follows various distributions.
2. To understand how stochasticity enters into population dynamics.
3. To incorporate human decision making into population models, and thus assess sustainability both from an ecological as well as socio-economic perspective.
4. To design and execute a scenario analysis of a hunter-prey system.

PART 1: **INTRODUCING STOCHASTICITY**

When you think, informally, of randomness, you might consider a magician (or charlatan) who asks you to think of a number between one and one hundred. As such, all numbers in that range would be equally likely to be chosen. But what he (and it usually is a he) means, is that you should choose an *integer* in that range. Even so, you may think that all integers [1, 2, 3, 4, 5, 6, 7, 8, 9, 10…] are equally likely to be chosen. If so, then you are drawing from a **uniform** distribution. The uniform distribution is not very useful in biology, however. Although it’s true to say that the number of babies a British woman will have over her lifetime will fall somewhere between zero and one hundred, it’s not a very informative statement. Rather, we can be far more precise.

The average British woman will have 1.90 children over her lifetime. Obviously, no woman will have precisely 1.90 children. Rather, 15% will have no children, 28% will have one, 27% will have 2, and smaller and smaller percentages will have three or more (**Figure 1**). This is because fecundity is a counting process, which follow the **Poisson** distribution.



**Figure 1:** The expected number of children per woman in Britain. The red line indicates the mean. Data from ONS, 2012.

Mortality, on the other hand, is an all-or-nothing, 0/1, yes/no process. It can only happen once to any organism. So we model it using the **binomial** distribution, which yields the probability of a certain number of “successes” occurring, given a set of independent trials and the underlying probability that any one of those trials will result in success. In this case, we’re considering the death of an individual to be a success, and each individual to be a trial. Thus, if we have a population of 1000 individuals, and each one has a 1% probability of mortality in a certain time interval, we can expect that, on average, 10 individuals will die in that interval. But, that value will vary. Just as not every British woman will give birth to 1.9 British children, not exactly 1% of the individuals will die in every timestep. To be precise, there is a 9% chance that 7 individuals will die, an 11% chance that 8 individuals will die, a 13% chance that 9 individuals will die, etc. Other outcomes are far less likely. The probability that only one individual will die, for example, is 0.04% (**Figure 2**)



**Figure 2. The expected number of deaths in a population of 1000 individuals, in which the per-capita mortality risk is 1%. The red line indicates the mean.**

Finally, the **normal** distribution. The normal distribution is unlike the preceding two, because it is a continuous distribution. The first two generate only integers, making them useful for births and deaths, respectively. The normal distribution is useful for many things, but we will mostly use it for individual size or population size. It’s useful because numbers drawn from a normal distribution centred on zero include mostly small numbers and a few big numbers. It’s thus useful for incorporating errors in measurement or estimation. If I sent you all out to count the number of sheep grazing on Dumyat, each of you would return with a different independent estimate. Let’s say that the mean you obtain as a class is 1472, with a standard deviation of 76. In other words, 67% of students obtained estimates between 1396 (1472-76) and 1548 (1472+76). We could then use these estimates, for example, as initial values of sheep population sizes in a projection model (i.e., as N0; **Figure 3**).



**Figure 3.** A normal distribution based on the estimations of 55 students of the number of sheep grazing on Dumyat. The vertical line indicates the mean, and the horizontal one the standard deviation of their estimations.

**Tasks for Part 1**

1. Explain the population model that is laid out beginning on lines 49 to your neighbours. What does each parameter mean? To which of the models that we’ve considered so far this semester is this one most similar?
2. Outline the role of demographic stochasticity and the effect it has on the model and the population size.
3. Calculate the probability that the population declines to less than a quarter of its initial size at the end of 50 years.
4. Outline the importance of modelling environmental and demographic stochasticity when making recommendations for population management and conservation.

PART 2: **SCENARIO ANALYSIS**

**Description of model**

We will use the logistic growth model throughout the scenario analysis:

where *Nt+1* is the population in the next time step, *Nt* the population in the current time step, *Bt* and *Dt* are effective birth and death rates, and *K* is the carrying capacity. Note that this is identical to the model from week 2, with *r\*Nt* replaced by *B*-*D.*

We add noise to the population dynamics in three ways. We draw *Bt* from a Poisson distribution, given the underlying probability of each individual in the population giving birth to new offspring and the number of individuals in the population.

Similarly, we draw *Dt* from a binomial distribution, given the probability of mortality of any individual in the population and the total number of individuals in the population.

This variation in *Bt* and *Dt* could be induced through environmental stochasticity, for example through weather, with very bad weather in some years affecting survival or subsequent fecundity.

Moreover, we admit in this model that human observers do not know the population size with absolute precision. We do so by assuming that the observed number of animals is a lognormally distributed variable, centred around the true population size, with a certain standard deviation (sd). Increasing this standard deviation means that human observers estimate the population size less accurately. The lognormal distribution is just like the typical normal distribution, but it is skewed so that it includes only positive numbers.

Thus, there are three sources of stochasticity in this model: Births, deaths and population size estimates.

**Hunting**

We simulate four hunting regimes: constant, proportional, threshold and adaptive.

* *Constant* means that the same number of animals (*h*) are hunted in every time step, regardless of the population size.
* *Proportional* means that a constant fraction of individuals (*prop*) are hunted in every time step. Thus, the number of animals extracted varies with the population size.
* *Threshold* is like proportional, except that a constant fraction of individuals is hunted, but only if the population size is greater than a certain threshold value (*thresh*). Otherwise, no hunting occurs.
* *Adaptive* takes into account the change in population size over the previous three time-steps to determine whether to increase or decrease the number of animals hunted. The sensitivity of the hunting rate to the change in population size can be varied with the parameter *flex*. If flex = 0, then this hunting regime becomes equivalent to *Constant*.

**Model outputs**

This model outputs several variables. The most obvious are the population trajectories without hunting (*Ntrue*) as well as trajectories under each of the four hunting regimes. Similarly, it outputs the numbers of individuals harvested in each timestep under each hunting regime. We further can calculate the mean yield for each hunting regime, being the average number of individuals hunted per timestep. Finally, we calculate the average inter-annual variation (AAV), which represents the degree of year-to-year variation in hunting offtake under each hunting regime. This is of interest, as hunters – and hunting regulators – prefer steady and predictable performance, rather than highly variable yields.

**Assignment**

Your task is to evaluate the four hunting regimes in terms of ecological sustainability as well as hunting benefits. The ideal regime is that which generates maximal hunting yield, with minimal inter-annual variation, while simultaneously maintaining the population size as large as possible. Thus, you are faced with a three-way optimization problem. Your evaluation should generate clear recommendations to hunting regulators as to the preferred hunting regime to implement, and the values at which the hunting parameters should be set. If you are ambitious, consider how changes to the population dynamics (for example, the rates of birth or death, or the carrying capacity) would affect your recommendations.

Write a brief but insightful scientific paper on your analysis of this hunter-prey system. In the **introduction**, clearly state the questions that your study will answer. Be sure to provide enough background so that the reader clearly understands their context. In the **methods**, briefly state how you manipulated the model. There is no need to describe the basis or development of the model itself. In the **results**, lay out your findings clearly, using tables or figures as necessary. In the **discussion**, interpret your findings in terms of your research questions. Did your findings support your hypotheses? What implications can be drawn from your study? Be sure that any figures are legible, well-labelled, and illustrate your findings. Extensive literature research is not necessary, however, you may find it useful to refer to some papers to interpret your results. Use no more than 1500 words in total (excluding figure captions and references).

During the practical sessions, I encourage you to work with your neighbours. Your report, however, must be written in your own words. Write your reports *independently*. Turn in this assignment using Turnitin ONLY by **Friday October 21st at noon**. There is no need to submit a hard copy. Indicate your identity with your student number, and only your student number.

**MARKS**

Introduction (20):

Hypotheses (10):

Methods (10):

Results (20):

Figures & Tables (20):

Discussion (20):

**Literature**

Here are a few suggested references for further reading. The first is on Succeed, the others are available at the library or through Google Books.

1. Bunnefeld, N., C. T. T. Edwards, A. Atickem, F. Hailu, and E. J. Milner-Gulland. 2013. Incentivizing Monitoring and Compliance in Trophy Hunting. Conservation Biology 27:1344–1354.
2. Matthiopoulos, J. 2011. How to be a quantitative ecologist: the ‘A to R’ of green mathematics and statistics. Book, John Wiley & Sons. Chapter 8.
3. Milner-Gulland, E. J., and J. M. Rowcliffe. 2007. Conservation and sustainable use: a handbook of techniques. Book, Oxford University Press. Page 260 and following, as well as 172 and following.