Exercise Hints and Solutions for Chapter 19

Agent-based and Individual-Based Modeling: *A Practical Introduction, 2nd Edition*

This document was substantially revised and corrected in March, 2022. Previous versions contained errors.

Exercise 2

Solutions to this exercise should use two techniques. First is to try several alternative traits, often of increasing complexity, run experiments to see which traits cause the model to reproduce which patterns, and draw inferences from the results about which processes are important. Second is to design traits that incorporate the actual biology of the system being modeled: can students develop traits based on the mechanisms and processes discussed in the Design Concepts section of the ODD description, considering all the advice given in Section 19.2?

The code we provide to students on the web site simply assumes individuals decide randomly whether to scout for a vacant territory each month. This random scouting trait causes the model to reproduce the group size distribution of Figure 19.2, but not the other two patterns. The mean age of scouting adults is not distinctly different from the mean age of all subordinates, and the number of forays declines from month 1 to 12 (because fewer subordinates are still alive each month). These results of the random trait should lead to the important inference that the group size distribution is a very robust pattern, being reproduced even when the key behavior is random, so it probably will not be very useful for distinguishing among alternative scouting traits.

The traits that students develop should include one that assumes birds are less likely to scout when they are older. Students might design a trait that simply forces the model to reproduce the second pattern, e.g., by assuming the decision to scout is stochastic but the probability of scouting decreases with age. Ideally, though, a trait should be based on the understanding that younger birds are less likely to become alpha in the home territory, so for them scouting for a new territory is a relatively more attractive option. A bird can become alpha in its home territory only if it outlives its parents and all its older siblings of the same sex; this is less likely for younger birds that have older, but still subordinate, siblings still in the territory. Hence, a trait might reasonably assume that the probability of scouting increases with the number of birds that must be outlived to attain alpha status at the current territory.

A highly mechanistic trait can be based on the same idea behind the Business Investor model’s adaptive trait: individuals decide whether to leave by predicting their expected success (here, probability of reaching alpha status) over some future time horizon, if they stay and if they scout. Here we develop such a trait; in the not-unlikely event that your students do not arrive at a similar trait it would be good to explain it to them.

The first issue in designing this trait is defining exactly what alternatives the individual woodhoopoes choose from. One alternative is clearly to stay in the home territory and not scout over the whole time horizon. The other alternative is whether to make a scouting foray this month, but to make a decision we also have to define what the individual does for the rest of the time horizon. This question is difficult because the subordinate could scout each month, or some months but not others…there could be very many different combinations of scouting and staying over the time until next breeding season, and evaluating them all would require a sophisticated optimization that is not justified by the uncertainties in the system. To make the decision trait tractable, we will use an assumption that is useful despite being clearly incorrect. We will assume that the second decision alternative is whether to scout this month if it then stays in the home territory for the rest of the time horizon. (But remember that the birds repeat the decision each month, so this assumption does not preclude birds from scouting in future months.) With this assumption, the probability of becoming an alpha by any future time is the probability of *either* scouting successfully this month *or* becoming alpha in the home territory because all elders die before the end of the time horizon.

The second issue is what to use as the time horizon. It might seem natural to use next December as the end of the time horizon because it is the next opportunity to reproduce. (An animal's ultimate objective is to reproduce.) However, it is important to understand that the woodhoopoes live a relatively long time and the current year is only a small part of their lifetime opportunity to reproduce. Because of assumption that an individual's probability of surviving for another month is always 0.98, its expected remaining life span is independent of its age. If, for example, we want to use a time horizon long enough that a bird is only 10% likely to live beyond it, we can set it to the number of months from now at which its probability of still being alive reaches 0.1. This time horizon is easily calculated: survival for any number of months n is 0.98^n, so if n is the number of months until the bird is 10% likely to still be alive then: $0.1 = 0.98^n$; or $\log(0.1) = n \log(0.98)$; so n is 114 months or 9.5 years. So a time horizon of 10 years would capture the entire life and reproductive potential of over 90% of birds.

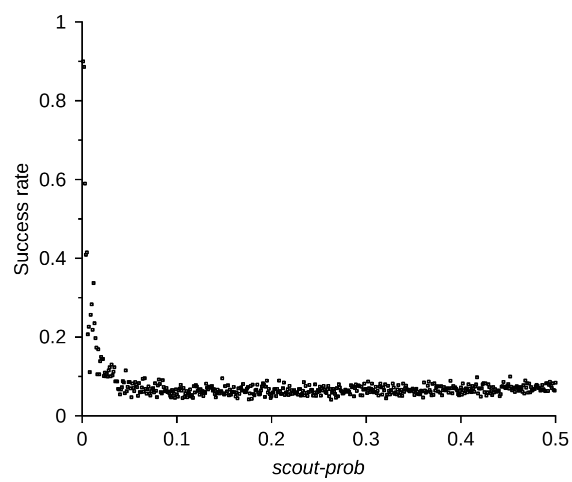
The information provided in the ODD description is sufficient to develop a trait in which a subordinate bird estimates its expected number of offspring over a future 10 years, for both the "stay" and "scout" alternatives—with one exception that we can work around. Here is one approach.

The following steps are repeated for the current year and each of the 9 subsequent years (i.e., for each value of the variable *breed-year* from zero to 9). To start, the subordinate's expected number of offspring over the time horizon if it does not scout (*offspring-if-stay*) and does scout (*offspring-if-scout*) are both initialized to zero.

- Calculate *months-till-breeding*, the number of months until December of the year being considered.
- Calculate the probability of becoming alpha by December of the year being considered, for a subordinate that stays in the home territory. This is the probability that all older birds of the subordinate's territory and sex die between the current month and that December *and* that bird itself does not die. (We use the term "elders" for older birds, including the alpha, of the same sex and territory as the bird making its decision.)
    - The probability of one elder dying within *months-till-breeding* months is 1.0 minus the probability of surviving *months-till-breeding* months, which is $S^{months\text{-}till\text{-}breeding}$ where S is the monthly survival probability (here, 0.98).

- If we assume that the survival of each elder is independent of each other, then probability of *num-elders* elders dying is simply the product of the probability of each dying. Therefore, the probability of all elders dying is $(1.0 - S^{months\text{-}till\text{-}breeding})^{num\text{-}elders}$.
- The probability that the bird making the decision does not die over *months-till-breeding* months is $S^{months\text{-}till\text{-}breeding}$.

- Calculate the expected number of offspring for the year being considered and add it to *offspring-if-stay*. The expected number of offspring for the current year is the probability that all elders die × the probability that the subordinate survives × the number of offspring when breeding occurs, which is 2.
- Calculate the probability of becoming an alpha during the year being considered if the subordinate goes scouting this month.
    - Successful scouting requires finding a vacant territory. We can model the probability of becoming alpha this way simply as *foray-success*, a new parameter for the probability of finding a vacant territory on a scout. But we need an estimate of *foray-success*, which is not given in the model description. (The ODD's *sensing* design concept in fact says that birds cannot sense whether territories are vacant nearby, but it is reasonable to assume birds behave as if they have some innate knowledge of about how often scouting forays are successful.) The group size distribution in Fig. 19.2 indicates that *foray-success* should be relatively low: few territories have fewer than 2 adults. One way to estimate its value is to observe the scouting success rate in the model when the scouting decision is made randomly. We should expect scouting success to depend on how often birds scout, so with a few simple changes to the code we can evaluate how the scout success rate (fraction of forays that find a vacant territory) varies with the probability of making random forays. The results of such an experiment (figure below) indicate that the fraction of forays that are successful does indeed decrease sharply as the number of forays increases, reaching a range of 0.06-0.08 when scouting is very common. We will therefore use a value of 0.1 for *foray-success*.



    - The probability of becoming alpha by staying in the home territory (P_t) when scouting is not successful is the same as for subordinates that do not scout: all elders must die. The probability is therefore $(1.0 - S^{\textit{months-till-breeding}})^{\textit{num-elders}}$.

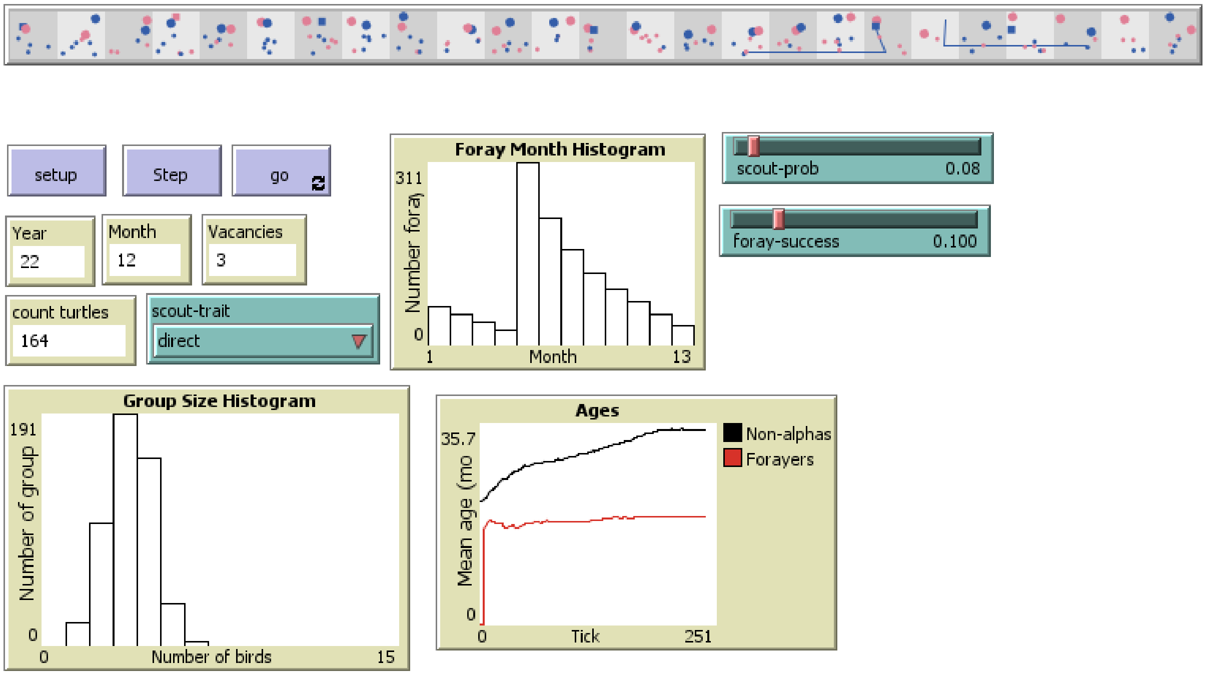
    - The probability of either of the above two ways of becoming alpha happening is (from basic probability theory) 1.0 minus the probability that neither happens. Therefore, the probability of becoming alpha by scouting this month, under our assumptions, is 1.0 – [(1.0 – *foray-success*) (1.0 - P_t)].

    - The probability of the subordinate surviving until the end of the year being considered must now include the one-time risk of undertaking a scouting foray. This survival probability is $S^{\textit{months-till-breeding}}$ × *scouting-survival*, where *scouting-survival* is the probability of surviving a foray (0.8).
- Calculate the expected number of offspring for the year being considered if the subordinate scouts and add it to *offspring-if-scout*. The expected number of offspring for the current year is the probability of becoming alpha × the probability that the subordinate survives × the number of offspring per breeding.

The scouting trait is therefore that subordinate adults should scout whenever their total expected number of offspring, over the 9+ years considered, is greater if they scout on the current month than the total expected offspring if they do not scout. We should now thoroughly explore this trait before putting it in the model, by seeing how the decision varies with the number of older siblings and the month. We can program the two probabilities in an Excel file, for example, identify the conditions under which birds should scout (`ForayTraitExploration.xlsx` in the instructor materials). Doing so indicates that, with the parameter values used here, birds should scout only (a) in months 5-12 when there are 2 elders, or (b) any time there are 3 or more elders. Varying *foray-success* changes the distribution of scouting among months, but for values around 0.1 scouting is least common just before and just after the breeding season. Hence, this trait is fairly robust to its one unknown parameter.

Another important observation from exploring this trait is that the difference in expected number of future offspring between scouting and staying is never large—never more than 0.05 expected offspring. So we should expect high variability in decision outcomes as assumptions are varied, and perhaps also low ability to predict behavior of the real birds.

This trait is implemented in the instructor materials code `Ch19-Ex2_WoodHoopoesWithTheories_2ndEd.nlogo`. Implementing this trait produces results such as these:


setup
Step
go
Year
22
Month
12
Vacancies
3
count turtles
164
scout-trait
direct
Foray Month Histogram
311
Number foray
0
1
Month
13
scout-prob
0.08
foray-success
0.100
Group Size Histogram
191
Number of group
0
0
Number of birds
15
Ages
35.7
Mean age (mo
0
0
Tick
251
Non-alphas
Forayers