Taking Flight: Modeling Condor Populations

Project Module Associated with
***Introduction to Computational Science: Modeling and Simulation, 2nd Edition* by**

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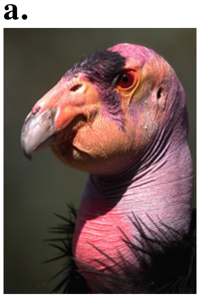
Project 1 Prerequisites*: Module 2.2, "Unconstrained Growth and Decay," and for Part d, section "Sensitivity Analysis for Age-Structured Example" of Module 13.3, "Time after Time: Age- and Stage-Structured Models"*
Project 2 Prerequisites*: for Part a, Module 13.4, "Probable Cause—Modeling with Markov Chains," and for Part b, section "Sensitivity Analysis for Age-Structured Example" of Module 13.3, "Time after Time: Age- and Stage-Structured Models"*
Project 3 Prerequisite*: Module 2.3, "Constrained Growth"*
Project 4 Prerequisite*: Module 11.4, "Introducing the Cane Toad – Able Invader"*

Introduction

Looking closely at the head of an adult California condor, you might think of it as unattractive, or even scary (Figure 1). The head and neck, lacking feathers, exposes somewhat garishly pigmented skin of yellow, pink, purple, or orange. Yet, if you see one, with its 9 ½ foot wingspan, soaring high in the air, you will marvel at its grace.

a.



b.

Figure 1 **a.** Condor (USFWS 2016) **b.** Condor in flight (NPS 2007)

These birds have flown over the North American continent for thousands of years, yet their numbers plummeted during the 20th century due primarily to the use of the insecticide DDT. During the 1980's, the 22 known birds in the wild were captured, maintained, and allowed to breed in captivity. In 1992, some adults were gradually reintroduced into their normal ranges in California. In 2016, 435 or so were known in the wild, and 160 were supported in captivity. Most of the wild populations are found in California, Arizona, Baja California, and Mexico (Defenders 2016, Cornell 2015).

Condors are very large vultures that may soar up to 15,000 feet altitude and travel 150 miles in search of food. Feeding on **carrion** (decaying animal flesh), the birds locate prospective sources using their excellent eyesight. They have a poor sense of smell, which is probably an advantage, given their diet. Furthermore, the lack of feathers in the head region makes it easier to keep clean after digging into a pretty messy dinner. Because they are social birds, you may see more than one at a time feeding, nesting, or bathing. With scarce food sources, the birds can eat their fill and store up to 3 pounds of meat in a specialized portion of their esophagus (**crop**) (Defenders 2016, Cornell 2015).

Condors reproduce very deliberately. After mating, the female will lay 1 egg, incubated by both parents for almost two months. The chick will fledge after about 6 months, but will remain dependent on the parents for at least another year. Thus, each adult pair may only mate every other year or so. Sexual maturity usually occurs at 6-8 years of age (Defenders 2016, Cornell 2015). With their inability to hurry the breeding process, it is little wonder numbers plummeted and recovery has been so problematic.

In the wild, condors face many hazards, most often stemming from interactions with human populations – power lines, hunting, habitat loss from housing developments or oil, gas exploration, etc. One of the most common threats comes from ingesting lead in their food from ammunition used by hunters or farmers who kill other animals (Defenders 2016).

Projects

1. Develop a system dynamics model for a California condor population taking into account seven groups, those in the seven individual years of pre-adult development (Year 0 through Year 6) and adults. Assuming equal numbers of males and females, only consider condor pairs. Suppose two pairs of Year 5 and two pairs of Year 6 condors are released into an area that has no other condors. Assume that the wild productivity rate (fecundity) for a female (or pair) is 0.3729 (fledglings/female)/yr and that this rate takes into account mortality in the first year. Consider possibly different pre-adult (years 1 – 6) and adult death rates. For each of the following situations, using a time step of one year, plot the number of juvenile females (Years 0 and 1), subadult females (years 2 – 6), adult females, and total number of female condors for at least 50 years, and discuss the results. Thus, in your model, adjust the productivity rate to be the rate at which an adult female has a female fledgling/yr.

- **a.** Suppose pre-adult and adult death rates are 0.086.
- **b.** Determine pre-adult and adult death rates that are equal and result in an equilibrium of less than 10 females.
- **c.** Suppose pre-adult death rate is 0.136 and adult death rate is 0.069.
- **d.** Starting with death rates of 0.086, determine the sensitivity of the total pair population to each of the death rates. That is, which has a bigger impact on the equilibrium total population, pre-adult death rate or adult death rate?

2. We can employ a Markov model to estimate the condor effective birth rate, or the rate at which a breeding pair reproduces to have a chick that lives until the next year with one or two tries. In estimating the birth rate, we consider two categories of condors, eligible (E) to reproduce and ineligible to reproduce (N). In a year, adult condors are in set E because the previous year they did not have a successful clutch or completed raising a chick. Those in set N were successful breeders last year, and so, will not mate this year. Thus, we employ a 2-by-2 transition matrix, T, to estimate next year's values, E_1 and N_1, from this year's, E_0 and N_0, as follows:

$$T\begin{bmatrix} E_0 \\ N_0 \end{bmatrix} = \begin{bmatrix} E_1 \\ N_1 \end{bmatrix}$$

We assume that birth of a chick can occur in early season or, in case of an initial failure, in late season. Let r be the probability that a pair has a successful attempt in which they produce a chick that lives until the next year. Thus, the total number of early-season chicks is rE. In case of an early-season failure, let a be the probability that such a pair will try to breed in late season. If they do, we assume the same probability, r, that this second breeding attempt will be successful. Thus, for late breeding, the pair must be unsuccessful in their first attempt and decide they will try again and be successful in their second attempt; so that the probability of the birth a successful late-season chick is the product of the probabilities of these three events (Oster 2016).

a. Assuming that $r = 0.5$ and $a = 0.5$, develop a state diagram and a transition matrix, T, for the system. Calculate T^{1000} to estimate the matrix to which T^n converges as n gets larger and larger. Let v_0 be a distribution vector of the fractions of eligible and ineligible condors, such as (0.2, 0.8), where the sum of the nonnegative elements is 1. Calculate v_{1000}, where $T^{1000}v_0 = v_{1000}$, to estimate the fractions of eligible and ineligible condors, as $n \to \infty$.

b. Use sensitivity analysis to see what parameter, r or a, has the greatest impact on the eventual fraction of ineligible condors, or those condors successful in having a chick.

3. To aid in the recovery of California condors, in some areas scientists at government environmental agencies have captured all or some of the animals and raised the young in captivity. In a process called "double clutching," the environmentalists remove the first eggs in the spring and feed the young using hand-puppets resembling the condor parent. Without a successful first effort, a breeding pair will often attempt a second. Consequently, the number of captive young is approximately doubled. Each year, 80% of the captive juveniles are released into the wild. However, if the number of captive condors exceeds its capacity, the facility will release all of the juveniles.

Develop a system dynamics model for captive and wild condors, using a time step of one year. For each, consider subpopulations of *Year 0*, *Year 1*, *Immature* (beyond year 1 but not mature), and *Adult* condors. Suppose release of the captive condors occurs during *Year 1*. Make simplifying assumption of equal numbers of male and female condors and that all adult condors mate. Table 1 lists project parameters and their values. The productivity rates are per mating pair, and so should be halved when considering individuals. Moreover, because of the challenges of calculating meaningful mortality rates for first-year chicks, the productivity rates indicate the average chicks per pair that survive to *Year 1*. Often mortality rates are difficult to establish. For each of the scenarios, plot the numbers of captive and wild condors for 50 years and discuss the results.

Description	**Value**
age captive begin breeding	7 yr
age wild begin breeding	8 yr
maximum number in captivity	150
wild carrying capacity	400
captive productivity rate (fecundity) assuming double clutching	1.8 yr^{-1}
captive productivity rate (fecundity) assuming no double clutching	0.9 yr^{-1}
wild productivity rate (fecundity)	0.3729 yr^{-1}

Table 1 Parameters for Project 3

a. Suppose year 1, immature, and adult birds have the same mortality rate, 0.086.
b. Suppose year 1 and immature birds have a mortality rate of 0.138, while adult condors have a mortality of half that amount, 0.069.
c. (Bustamante 1996) found a mortality of 65.9% for year-1 bearded vultures. Use this mortality and immature and adult mortality of 0.086.
d. Consider year 1, immature, and adult mortalities of 0.659, 0.138, and 0.069, respectively.
e. Consider year 1, immature, and adult mortalities of 0.659, 0.099, and 0.099, respectively.
f. Under the assumptions of Part d, suppose that a program of double-clutching persists for five years. Afterwards, all captive birds are returned to the wild. Compare the number of wild condors for this scenario to that in Part d.

4. Develop an agent-based model of a wild California condor population, using the parameters of Project 1.

References

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