Chapter 3

Management of renewable resource harvesting

1. The northern right whale dolphin (*Lissodelphis borealis*, Fig. 3.1) is often caught in the northern Pacific Ocean by the big high seas driftnets used for fishing commercial species. Mangel (1993) provides information on the demographics and the capture of these dolphins. The dynamics, when there is no fish harvesting, can be described by a generalized logistic model of this kind

\[
\frac{dN}{dt} = rN \left(1 - \frac{N}{K}\right)^z
\]

with \(K = 900,000\) dolphins and \(z = 2.39\). Calculate the abundance \(N_0\) at which the maximum sustainable yield of dolphins would be obtained by an appropriate harvesting policy. The exercise is purely theoretical because hunting marine mammals should be avoided.

![Figure 3.1: The northern right whale dolphin.](image)

2. The common pheasant (*Phasianus colchicus*) was introduced into Protection Island in 1937. By following the demographic growth of this bird along time it has been possible to obtain the relationship linking the population rate of increase to the population size (see Fig. 3.2)

Assume that pheasant hunting is permitted and the regulation policy is based on granting licenses. You know that

- effort is measured as No. of operating hunters
- the catchability coefficient is 0.01 No. hunters\(^{-1}\) year\(^{-1}\)
- only half of licensed hunters is actually hunting in the average.

Calculate the number \(L\) of licenses to be granted that guarantees the maximum sustainable yield and the corresponding pheasant population size at equilibrium. Finally calculate the effort \(E_{ext}\) that would lead population to extinction.
3. The graph shown in Fig. 3.3 reports the stock-recruitment relationship for the sockeye salmon (*Onchorhynchus nerka*) of river Skeena (British Columbia, Canada). Approximately determine the maximum sustainable yield (as million fish).

4. McCullough (1981) studied the dynamics of grizzly bears (*Ursus arctos*) in the Yellowstone Park. He reports the stock-recruitment curve shown in Fig. 3.4, which links the number $P_k$ of adult bears in year $k$ (namely, the individuals that are 4-years-old or older in year $k$) to the recruitment ($R_k$), namely the number of adult bears four years later.

Assume that the Park management allows hunting of adult grizzlies according to the following policy

$$H_k = \begin{cases} 
0 & \text{if } R_k \leq 35 \\
0.5(R_k - 35) & \text{if } R_k > 35 
\end{cases}$$
so that a minimal recruitment of 35 adult bears is guaranteed. Evaluate the implications of implementing this policy on the population dynamics.

5. There has been an international debate in the past regarding the opportunity of catching Antarctic krill (*Euphausia superba*, Fig. 3.5), a small crustacean that forms huge swarms in the waters surrounding Antarctica and is a fundamental food for many baleen whales. As the whale stocks have collapsed (and their recovery following the international moratorium on whale hunting will take decades), some researchers proposed that krill might be fished without impairing the functioning of the Antarctic ecosystem.

Discuss the problem by writing a simple prey-predator (krill biomass-whale biomass) of the Lotka-Volterra kind, in which the prey grows in a logistic way. Assume that krill is fished with a constant effort $E$, while hunting of whales does not take place. Determine the stable equilibria of the prey-predator system while the parameter $E$ varies. Find out how the biomass of the sustainable krill catch varies for increasing $E$.

6. Assume you want to rationally regulate deer hunting in a grassland where the animals can extensively graze. To that end, describe the resource (grass) - consumer (deer) system dynamics by the equations

$$\frac{dG}{dt} = w - d_G G - pGD$$

$$\frac{dD}{dt} = -d_D D + epGD - uD$$
where $G$ and $D$, respectively, indicate the biomass of grass and of deer (tonnes) and $u$ is the mortality rate due to deer hunting. You know that

- $w = \text{net primary production} = 100 \text{ tonnes year}^{-1}$
- $d_G = \text{grass death rate} = 10 \text{ year}^{-1}$
- $p = \text{grazing rate coefficient} = 0.2 \text{ tonnes year}^{-1}$
- $e = \text{conversion coefficient} = 0.1$
- $d_D = \text{deer death rate} = 0.1 \text{ year}^{-1}$

Calculate the sustainable yield of deer biomass as a function of hunting mortality $u$. Then find the maximum sustainable yield.

7. Fig. 3.6 shows the relationship between the number of pups given birth every year ($P$) and the reproductive adult stock ($S$) for a population of harp seals ($P. groenlandicus$) of the Northwestern Atlantic (Carl Walters, personal communication). The pups were harvested for their priced fur (the slaughter is still going on even if the European Union and more recently Russia have banned the import of seal products). About 50% of the pups would survive up to age 4 years if none were killed; animals 4-years-old or older ($S$) have an annual mortality that is approximately 12%, if both natural mortality and hunting is accounted for.

![Figure 3.6: The stock recruitment relationship of a harp seal population in the Northwestern Atlantic.](image)

Find out the equilibrium population size if the pups are not harvested. Estimate the number of pups produced every year given such an equilibrium population. Calculate, in case pups were harvested using an annual quota, the maximum sustainable yield and the corresponding adult population that would be necessary to produce such a yield.

Assume then that for several years the adult population equals 600,000 individuals; if 100,000 pups were harvested every year, what would the population dynamics be in the subsequent 4 years? What if the quota were increased to 200,000 pups every year?

8. The whales of the genus $Balaenoptera$ have been severely depleted by the extensive hunting carried out during the twentieth century. A very rough way of measuring their total biomass is the Blue Whale Unit (BWU), adopted by the International Whaling Commission which equated two fin whales and six sei whales to one blue whale. For the complex of these whales one can use a Schaefer model (logistic growth of whales and harvesting rate proportional to the product of effort
and whale stock). The effort was measured as the total number of hunting days per year. Assume the following parameters

(a) \( K = \text{carrying capacity} = 400,000 \text{ BWU} \)
(b) \( r = \text{intrinsic instantaneous rate of increase} = 0.05 \text{ year}^{-1} \)
(c) \( q = \text{catchability coefficient} = 1.3 \times 10^{-5} (\text{hunting days})^{-1} \)

and calculate the bionomic equilibrium under the hypothesis that the opportunity cost of one hunting day is € 5,000 and the selling price of one BWU is € 75,000.

9. The dynamics of the stock of the European hake (\textit{Merluccius merluccius}, Fig. 3.7) of the Adriatic sea can be described by the Schaefer model (see problem 8). Levi and Giannetti (1973) estimated the following demographic parameters:

\( K = \text{carrying capacity} = 5,000 \text{ tonnes} \)
\( r = \text{intrinsic instantaneous rate of increase} = 1.7 \text{ year}^{-1} \)

They also used the tonnes of consumed fuel per year as a measure of effort and estimated the catchability coefficient as \( q = 2 \times 10^{-5} (\text{fuel tonne})^{-1} \). Assume that the selling price of hake is € 6,000 per hake tonne, while the opportunity cost is \( c = € 140 \) per fuel tonne. Find the values of the hake stock and the effort at bionomic equilibrium. Then calculate the effort that would guarantee the maximum sustainable profit and the corresponding stock, catch and profit.

10. The dynamics of the fin whale (\textit{Balaenoptera physalus}, Fig. 3.8) is reasonably well described by the following generalized logistic model (\( N \) is the whale numbers)

\[
\frac{dN}{dt} = rN \left(1 - \frac{N}{K}\right)^a
\]

with \( r = 0.06 \text{ year}^{-1} \), \( K = 400,000 \) and \( a = 0.143 \). This stock is now protected, because it has been overexploited. Assume that, once the stock recovers (which will take several decades), hunting is permitted again, but is regulated. Implement a rational management scheme based on the information that the catchability coefficient is \( q = 1.3 \times 10^{-5} (\text{hunting days})^{-1} \), the price of one whale is € 40,000, the opportunity cost of one hunting day is € 4,000.

Find the effort \( E_0 \) that maximizes the sustainable profit, and the corresponding profit. Suppose you want to utilize a tax \( \tau \) (which is levied on each caught whale) as a regulation tool. Calibrate \( \tau \) so that effort stabilizes to the same \( E_0 \) you have already calculated.

Figure 3.7: The European hake \textit{Merluccius merluccius}.

Figure 3.8: The fin whale \textit{Balaenoptera physalus}.
11. Consider an open-access renewable resource, which is simply regulated by imposing a tax on the net profit obtained by each economic operator exploiting the resource. Comment on the efficacy of such a regulation method by using H. S. Gordon’s theory on open-access resources.

12. One of the main tenets of social welfare is progressive taxation. Assume that decision makers want to levy a progressive tax on the amount of biomass removed. The tax is structured as follows

$$\tau = \begin{cases} 
0 & \text{if } Y \leq Y_0 \\
\tau_{\text{max}} \frac{Y - Y_0}{Y} & \text{if } Y > Y_0
\end{cases}$$

where \( \tau \) is the amount that is levied on each unit of biomass being harvested and \( Y_0 \) is the biomass yield below which the exploiters are exempted from paying taxes. Discuss the efficacy of this regulation method by using a Gordon-Schaefer model (logistic demography, harvest proportional to effort times biomass, and bionomic equilibrium).

13. In the forested areas of North America the beaver (\textit{Castor canadensis}), which is no longer hunted for its fur, is becoming an important factor of nuisance to timber production. In fact, this herbivore can fell mature trees up to a diameter of 40 cm (Fig 3.9). A cost-benefit analysis estimated the annual damage of one beaver to be $ 45. Assume that the local authority wants to implement a culling policy in an area where the beaver carrying capacity is 1 individual km\(^{-2}\) and the intrinsic instantaneous rate of demographic increase is 0.3 year\(^{-1}\). Culling is expensive and the cost \( C \) can be evaluated as dollars per year per km\(^2\). \( C \) can be assumed to be proportional to the inflicted mortality rate \( m \) [year\(^{-1}\)] and inversely proportional to the beaver density \( N \) [No. of beavers km\(^{-2}\)], because capturing beavers is harder when their density is lower. Specifically, assume \( C = 2.5m/N \).

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{beaver_felling_tree.jpg}
\caption{A beaver felling a tree.}
\end{figure}

Find the best mortality rate, namely the one that minimizes the sum of the damages to timber plus the cost of culling. Estimate the beaver density at equilibrium corresponding to the optimal culling rate.

14. A tree species can be harvested for producing either pulpwood or sawlogs. Fig 3.10 reports the net profit that can be obtained from clear-cutting a forest lot at different ages. Assume that the discount rate is zero and find out the optimal rotation periods for the two alternatives. Evaluate whether it is more convenient to produce pulpwood or saw-logs.
Figure 3.10: Net profit per hectare as a function of age for a tree species that can be harvested for producing pulpwood or saw-logs.