Lecture 31: Oysters in Chesapeake Bay

Learning objectives

✓ Use a logistic DE to study a population and make predictions

✓ Make recommendations to government or invested parties based on modelling predictions

Scientific examples

✓ Over-harvesting oysters

Maths skills

✓ Understand the logistic DE and its solution

Case Study 27: Overfishing annoys an oyster

- Chesapeake Bay is a large estuary on the east coast of the United States, near the states of Virginia and Maryland. The bay has a surface area of more than 11000 km^2, with a shoreline length of more than 18000 km.
- In the past, the bay supported a diverse range of flora and fauna, including an abundant shellfish population, most notably oysters. However, it has experienced serious environmental degradation due to over-use, overfishing, and polluted runoff from agriculture, urban areas and industry.

Photo 11.3: Oysters. (Source: MG.)

- Substantial *marine dead zones*, which are areas of water so low in oxygen that they are unable to support life, are often found within the bay.
- Harvesting oysters is a long-term commercial industry in Chesapeake Bay, however, the size of the population (and hence the harvest) has drastically reduced, due to over harvesting and environmental damage; see Figure 11.6.

disease

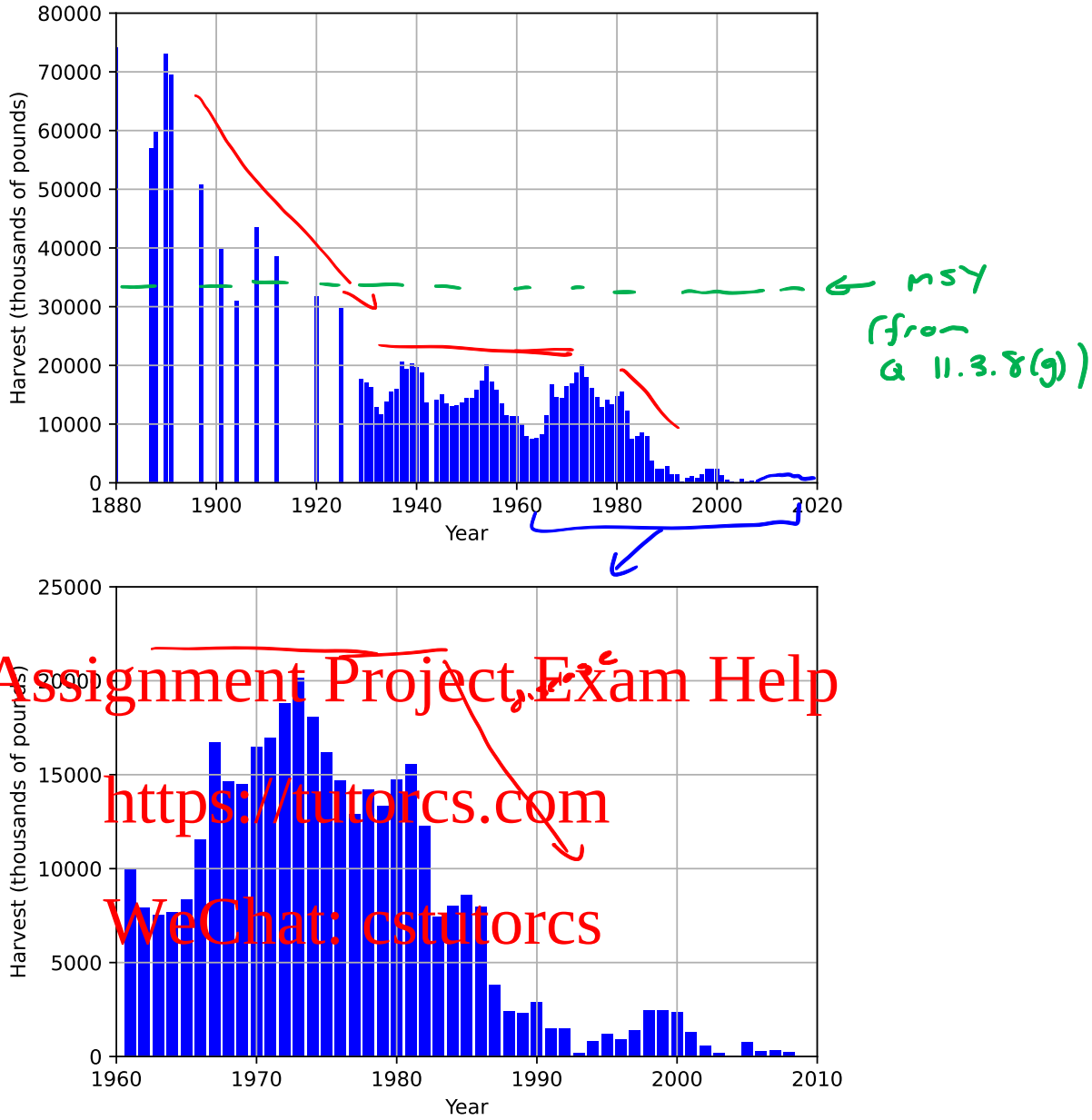


Figure 11.6: Annual Chesapeake Bay oyster harvests. Top: 1880 – 2008. Bottom: 1960 – 2008.

- Between 1982 and 2008, the value of the oyster harvest declined by 88%.
- Considerable research, money and education are being devoted to developing and implementing a sustainable, comprehensive management strategy.
- Figure 11.6 shows the historical annual official oyster harvest data for the Maryland part of the bay.
- The paper [54] studied the population of market-sized oysters in the Maryland part of the Chesapeake Bay.

$N' = r\left(1 - \frac{N}{K}\right)N$ logistic DE

- Using data from 1994 – 2007, researchers found that the effective unconstrained growth rate of market-sized oysters is around $r = 0.133$ per year.

If unconstrained $N' = rN$

- The estimated carrying capacity of the Maryland part of the bay is around 5×10^9 market-sized oysters.

Question 11.3.8

(a) Write a logistic DE for the population $N(t)$ of market-sized oysters, assuming no harvesting.

Logistic DE: $N' = r\left(1 - \frac{N}{K}\right)N$

$N' = 0.133\left(1 - \frac{N}{5\times10^9}\right)N$

(b) In 2007, the population of market-sized oysters in Chesapeake Bay was 81×10^6. Find the annual increase in the population size at that time.

$N = 81\times10^6$ (population of oysters)

Substitute into logistic DE:

$N' = 0.133\left(1 - \frac{81\times10^6}{5\times10^9}\right)81\times10^6$

$= 1.1\times10^7$ year^{-1} = 11 million/year

$N' \sim \frac{\Delta N}{\Delta t}$ (no units; units: years)

(c) The 2007 harvest was 50×10^6 oysters. Is this sustainable? Why?

We have 50 million oysters harvested in 2007 but a growth rate of only 11 million/year. Not sustainable – harvesting about five times the number that grow.

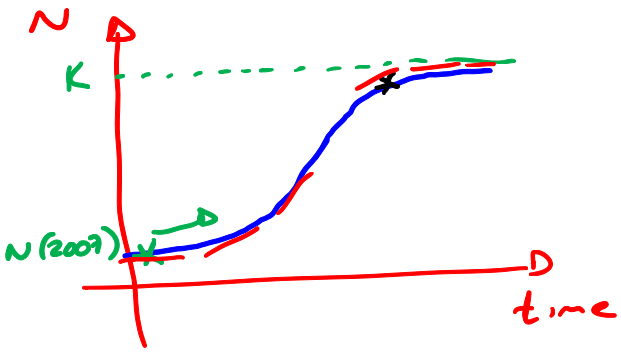
(d) Find the largest number of oysters that could be harvested *from the 2007 population* each year without reducing the total population.

The largest number to sustainably harvest is N', in 2007, $N' = 1.1\times10^7$/year. Maximum harvest is 1.1×10^7 or 11 million oysters

Question 11.3.8 (continued)

(e) If there was no oyster harvesting conducted for a few years, how would your answer to Part (d) change? Why?

As oyster population is very small, N would increase (approximately exponentially), and thus N' increases. If more grow, then more can be harvested



(f) In resource management, especially fisheries management, the *Maximum Sustainable Yield* (MSY) of a population is defined to be the *largest possible harvest size that could be maintained indefinitely*. Explain how the MSY relates to population growth rates. What is the **population size** at which the MSY can be sustainably harvested?

Maximum sustainable yield is when $N = K/2$
(this is when N' is a maximum — curve has the largest slope)

We have $N = \frac{K}{2} = \frac{5\times10^9}{2} = 2.5\times10^9$

(g) Use logistic DE to find MSY:

$MSY = N' = 0.133\left(1 - \frac{2.5\times10^9}{5\times10^9}\right)2.5\times10^9$
(when $N = K/2$) $\simeq 1.7\times10^8$ /year
$= 170$ million /years

Question 11.3.8 (continued)

(g) Find the MSY of oysters in Chesapeake Bay. Noting that there are around 5 oysters per pound, comment on the historical harvest rates in Figure 11.6.

(see above)

we found $N' = 1.7 \times 10^8$ /year

$= 1.7 \times 10^8$ /year $\frac{1 \text{ lb}}{5 \text{ (oysters)}}$

$= 3.3 \times 10^7$ lb/year

$= 3.3 \times 10^4 \frac{\text{thousands lb}}{\text{year}}$

$= 33000 \frac{\text{thousands lb}}{\text{year}}$

(h) A logistic growth model of a population with unconstrained growth rate $r = 0.133$ per year, current population $N_0 = 81 \times 10^6$, carrying capacity $K = 5 \times 10^9$ and no harvesting predicts the following population:

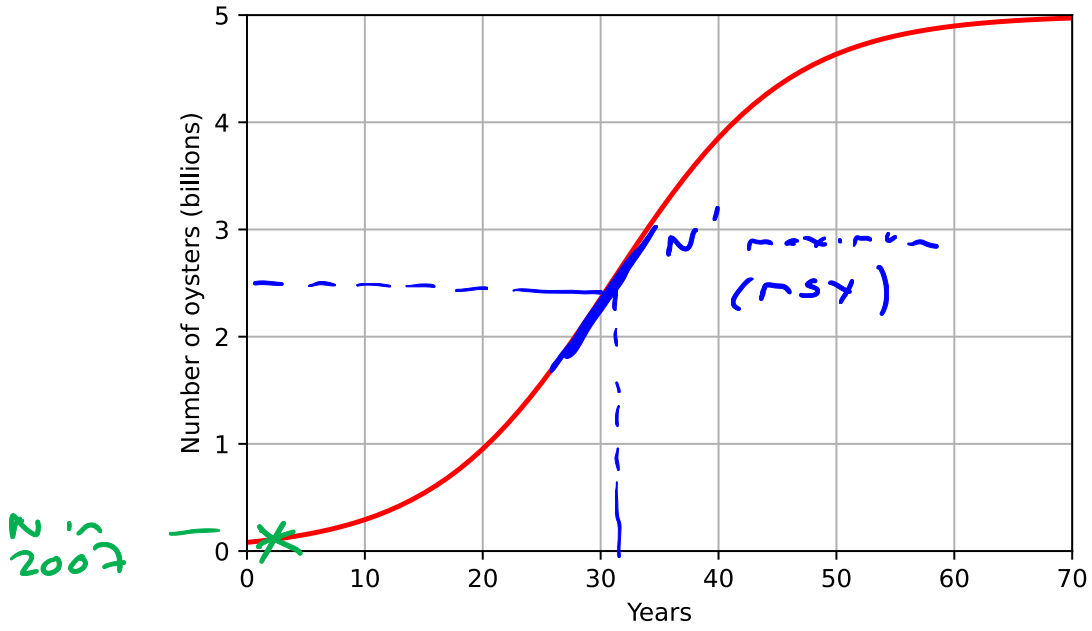


Figure 11.7: Logistic growth of the Chesapeake Bay oyster population with no harvesting.

***Question** 11.3.8 (continued)*

Make some brief recommendations to assist the government with long-term oyster stock management in Chesapeake Bay.

- Don't harvest for a few years (loss of income for industry)
- Limit harvest
- harvesting plan
- oyster farm (increase stocks)

Photo 11.4: Over-exploited? (Source: MG.)

***Question** 11.3.8 (continued)*

The 2008 paper [54] considers the economic value ("net present value") of the oyster industry, which also considers expected net returns of future harvests. They explain that unrestricted harvesting is unsustainable. They recommend that decreasing harvesting rates will increase the net present value, and shutting down the fishery for a number of years will allow stock to recover and significantly increase the net present value. They noted:

- As a result of habitat degradation, they may have overestimated the carrying capacity, so to test the sensitivity of the results to this parameter, they re-ran the models with a reduced carrying capacity and achieved a near identical optimal harvest rate as the original model.
- To test the sensitivity of their results to the intrinsic growth rate, they tested different growth rates. For example, even when cutting the growth rate in half, the net present value for the optimisation model's recommendation was still six times greater than the net present value for the unrestricted harvesting policy.

Given what you know from the philosophy of science component of the course about models being strictly false, how does the authors' clarification help give confidence in their recommendations?

model is robust as they tested the sensitivity to the various input parameters.

End of Case Study 27: Overfishing annoys an oyster.