Sustainability, Feedback and the Tragedy of the Commons

EL2220

Abstract

Feedback is a key concept in control theory, but is also fundamental to understanding sustainability, and in particular how resilient biological systems are influenced from outside disturbances, including those caused by human activities. The tragedy of the commons is a term describing cases where self interest leads to actions that are bad for everyone. In this seminar you will explore the connection between sustainability, feedback and the tragedy of the commons by investigating a scenario set in the fishing industry. You will explore it both from a more technical modeling-and-analysis perspective, and from a more conceptual policy perspective.

Note: The key learning outcome for this task is not control theory, but sustainability. Thus you are allowed to work in **groups of 1-3 persons**, and also discuss with other groups (but not copy solutions) if you find the control theory parts difficult. Finally, you might draw inspiration from the following material[1].

[1]The following links are from the course EL2620, however you should be able to solve the problems without having taken the course, using your overall knowledge of differential equations.
`https://people.kth.se/~jonas1/el2620/notebook/simulation/solve_ode_python.html`,
`https://people.kth.se/~jonas1/el2620/notebook/simulation/solve_ode_matlab.html`,
`https://people.kth.se/~jonas1/el2620/notebook/tutorials/equilibria.html`,
username:student, password:el2620,
This youtube link explores the same theme `https://www.youtube.com/watch?v=p_di4Zn4wz4`

1 Modeling and analysis of sustainability of system

In this section you will first see an example of a so-called predator-prey model involving wolves and moose. Then you will be asked to make your own model of a fishing industry scenario and explore the equilibrium and stability of it.

1.1 A predator-prey simulation

Explore the simulation of wolves and moose available online here[2], and complete the following tasks.

Reflection tasks:

a Describe in you own words how the growth of each species seems to depend on the number of both species.

b What would happen if you completely removed one of the species?

1.2 Modeling a fishing scenario

In this task you will create a dynamical model of the number of fish $x \in \mathbb{R}_+$ and the number of fishing boats $y \in \mathbb{R}_+$ in the deep sea (ignore the data on costal areas), based on the data in Figures 1 and 2. Let the maximum number of fish be $x_{\max} = 2000$ (in the appropriate units).

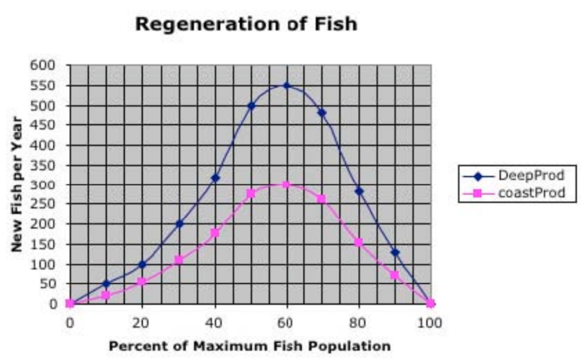

Figure 1: The regeneration of fish as a function of the number of fish.

Reflection tasks:

[2] `https://insightmaker.com/insight/2068/Isle-Royale-Predator-Prey-Interactions`

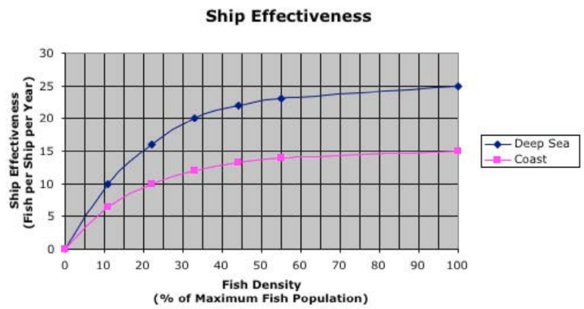

Figure 2: Fishing boat effectiveness as a function of the number of fish.

a *How fast do the fish re-generate?* Given the blue curve in Figure 1, find an approximation $f_r(x)$. It does not have to be exact, thus there are many ways to do this. Use your imagination. If you can try a few different approximations that is even better. If it seems difficult, you might find inspiration in its similarity to $x^2(1-x)$

b *How effective are the ships?* Given the blue curve in Figure 2, find an approximation $f_e(x)$ of the ship effectiveness in the deep sea. If it seems difficult, you might find inspiration in its similarity to $x/(1+x)$.

c *Create a model of the dynamical system.* Describe the time evolution of x with a differential equation $\dot{x} = f(x, y)$, also depending on the parameter y, the number of fishing boats. Use your expressions for $f_r(x)$ and $f_e(x)$ above.

d *For a fixed number of fishing boats, what is the equilibrium fish population?* Determine the set of equilibrium points of x and their corresponding regions of attractions for some different (interesting) fixed values of y. Remember that you are using approximations, so the precision is not important ($\pm 10\%$ is totally fine), but the overall behavior is. Thus you are free to use any numerical or analytical method you like.

e *Is there a tipping point if the number of boats keep increasing?* The IPCC AR5[3] defines a tipping point as an irreversible change in a (climate) system. Imagine the number of fishing boats y was very hard to control for some reason, and slowly rising (in a way that is similar to the carbon dioxide in the atmosphere). Would there be a tipping point, and if so, what would the corresponding change be?

f *What happens if the number of fishing boats depend on the amount of available fish (profit)?* Imagine that the number of fishing boats y is not static, but depends on the

[3] `https://en.wikipedia.org/wiki/IPCC_Fifth_Assessment_Report`

profit of fishing, such that fishing companies buy more boats if fishing is profitable. Thus, let $\dot{y} = k_y y(f_e(x) - c)$, where c is the amount of fish needed to pay for keeping the boat in operation and k_y is the responsiveness of the fishing industry to falling or rising profits. Now we have a 2-dimensional system where both the number of fish and the amount of boats vary over time. Investigate the system behavior for $k_y \in \{0.1, 1\}$ and $c \in \{20, 24\}$. One way of investigating system behavior is to plot state trajectories, by simulating the system, in the 2D state space (x, y), similar to the examples in Figure 3, note that plotting many trajectories in the same figure often gives a better overview.

What will happen to the number of fish and fishing boats for the different parameter combinations? Is there a stable equilibrium? Is there an unstable equilibrium? (how do you tell the difference?) Will both fish and fishermen all die out?

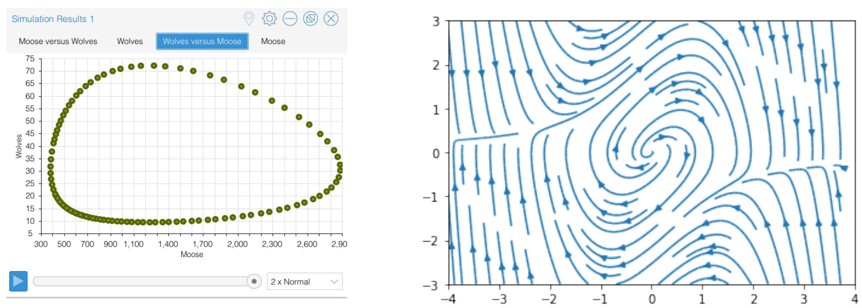

Figure 3: Examples of numerical state trajectory analysis of the Wolves and Moose system mentioned above (left) and a so-called Van der Pol oscillator (right).

g Imagine fishing boat technology is slowly improving over time. This can be modelled by the break-even catch size c decreasing. What would this mean for the fish?

h What would subsidies for struggling fish industries lead to, given your model?

2 Policies for a sustainable system

Reflection tasks:

a Watch these two video lectures on sustainability and systems[4][5].

[4] `https://youtu.be/c9p4yyTT1PQ`
[5] `https://youtu.be/E2PIZ4592gI`

b Check these examples (EIB, 2025)[6] of provisioning, regulating, supporting and cultural ecosystem services to deepen your understanding of the concept.

State three examples of ecosystem services that you have "used" today.

c "The tragedy of the commons" is used as an example of a system collapse in the video lecture Complex systems above. Read more real-life examples of the tragedy of the commons in this list (Spooner, 2012) [7].

How does the "The tragedy of the commons" relate to the fishing example above?

d Consider the data on stock and catch of Norwegian spring spawning herring in Figure 4. Given your own modeling and analysis above, what can you say about the data?

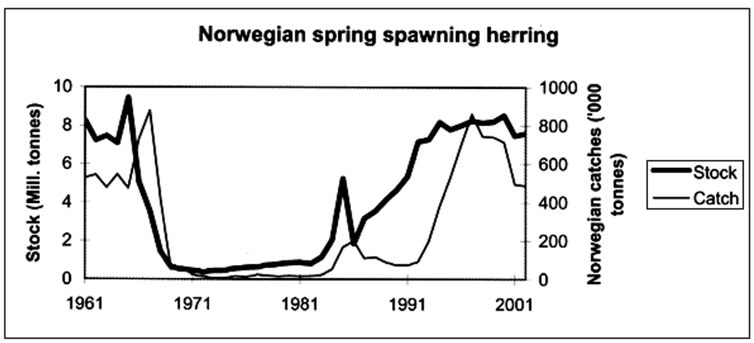

Figure 4: Catch and estimated stock of Norwegian spring spawning herring.

e What might happen if fishing companies responded to low profitability with moving their fleet to different parts of the ocean, such as when the EU started fishing outside West Africa[8]?

f In 2009, Elinor Ostrom was awarded the Nobel Prize in Economics. Her work shows how commons can be handled to prevent resource depletion and individual behavior which is contrary to the common good of all users (Nobel Media AB, 2014). You can find a simplification of her eight principles in the following link (Williams, 2018)[9].

[6] https://www.eib.org/en/stories/ecosystem-service-nature

[7] http://www.dummies.com/education/science/environmental-science/ten-real-life-examples-of-the-tragedy-of-the-commons/

[8] https://www.seafoodsource.com/news/environment-sustainability/eu-fishing-agreements-accused-of-contributing-to-overfishing-in-west-africa

[9] https://earthbound.report/2018/01/15/elinor-ostroms-8-rules-for-managing-the-commons/

Use the principles of Ostrom's work to describe measures that could hypothetically prevent a system collapse in our fishing system. Comment briefly on the implementation of all eight principles.