Encyclopédie de l'environnement

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Mathematical models can help to better manage fishing

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Fishing provides an important part of the food for people in some developing countries. This can lead to a worrying cascade of overfishing, collapsing catches and rising market prices, and the extinction of many species. How can we prevent this situation from becoming catastrophic and, on the contrary, stabilize it?

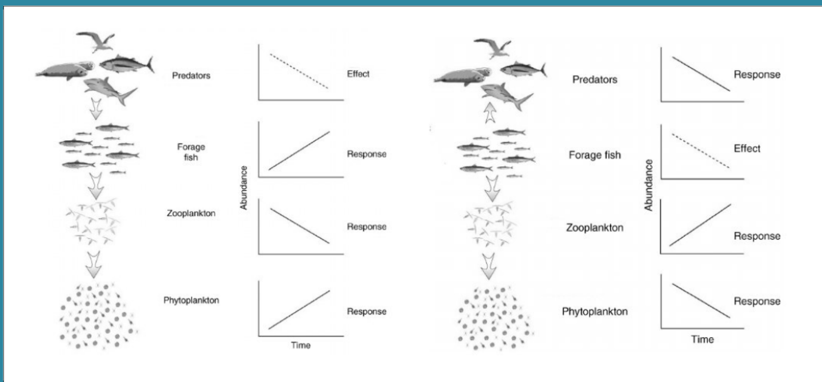
Mathematical modelling, by coupling ecological and economic dynamics, provides a better understanding of the dynamics of fisheries systems. It is presented here in a basic way and illustrated by the particular case of thiof, an emblematic species threatened in Senegal.

Examples of parameters:

Biomass*; Fishing Effort or Investment in Fishing;* ***Catch Rate or "Catchability"****; Rate of Growth of the Fish Population;* ***Fishing Quota****; Price on the Market;* ***Operating Costs****; Demand and Supply;* ***Spatialization of Fisheries***

1. Trophic interactions within marine ecosystems

4. Study the first two figures and draw a conclusion regarding a structuring element of marine ecosystems.



Trophic interactions within marine ecosystems depend on the size of individuals.

An exploitation targeting species according to their size will have cascading effects on all trophic levels of a marine ecosystem.

2. Basis of the fishing economy

5. Fill in the sentence with the following words:

level of abundance / cost / extinction / decreases / increases / exploitation / exploitation / species

In theory, the exploitation of a species can lead to its extinction if its price increases faster than the cost of its exploitation when the level of abundance decreases.

3. A simple mathematical model of the evolution of the biomass of an exploited species

The management of marine resources must be based on decision-making tools that enable managers and decision-makers to take measures for the conservation and optimal exploitation of fisheries. Mathematical modelling makes it possible to develop such tools in order to predict the effects of coastal development and fisheries control measures.
Mathematical models in fisheries are based on assumptions about the production and extinction mechanisms of harvested species.

6. Pay attention to the following mathematical model.

a. Identify the left member of the equation, as well as the two terms of the right-hand side of the equation.

b. Match the parameters (r, K, q, E), that are constants, with the elements they represent.

Left member of the equation: the derivative of biomass as a function of time (dx/dt) (*x(t) is the only variable – the biomass of the exploited species, depending on the time variable t*) > it represents the rate of variation of biomass.
The right-hand side of the equation has two terms: a biomass production term (growth of the biomass of the fish stock) and an extinction term (capture by fishing).

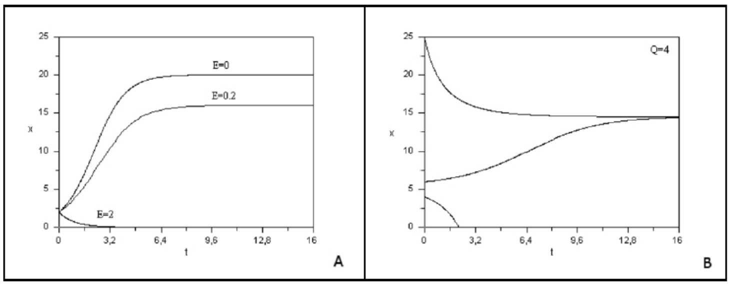
$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right) - qxE$$

r	Rate of growth of the fish population.
K	Carrying capacity : Equilibrium biomass towards which the stock would tend in the absence of fishing.
q	Catchability (or catch rate).
E	Investment in fishing (or Fishing Effort).

7. Another method of exploitation is to set a fishing quota per unit of time.
The previous model, assuming a catch with constant quota represented by parameter Q, is thus altered.

Looking at the figures below, would you advise unconstrained fishery or fixed quota fishery?

$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right) - Q$$



A fixed quota fishery is more risky than an unconstrained fishery because it can lead to the extinction of the species.

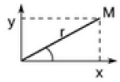
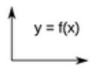
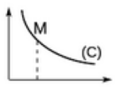
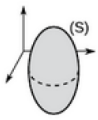
The study of this model shows that even a low quota can generate an "Allee" effect, *i.e.* below a threshold, the population quickly goes into extinction. Figure 6B [11] shows the evolution over time of the biomass of the resource under different initial conditions. With an initial condition chosen below a threshold, the population disappears. The great variability of environmental conditions in the marine environment from one year to the next can induce a passage below a threshold and irreparably lead the exploited species to extinction. In the 1970s, whaling was allowed freely, with the effect of causing a very significant drop in its numbers. These mathematical models have alerted decision-makers to the risks of fishing with a fixed quota.

4. Taking economic aspects into account: bio-economic models

To go further, read the full article.

Vocabulary: ***Do you Speak Science?***

x, p f(x) = p f(x), p	inconnue, paramètre ⇔ *unknown, parameter* équation ⇔ *equation* [1er, 2e] membre de l'équation ⇔ *[1st, 2nd] member/side of the equation*
f(x) = 0 g(x, y) = 0	équation à [1 inconnue, 2 inconnues] ⇔ *equation in [1 unknown, 2 unknowns]*
types de fonctions ⇔ *types of functions*	
y = f(x) f(x,y) = 0	fonction [explicite, implicite] ⇔ *[explicit, implicit] function* (oralement) *f* de *x* [et *y*] ⇔ *(orally)* f *of* x *[and* y*]*
y = f(x) z = g(x,y)	fonction [d'une seule, de plusieurs] variable[s] ⇔ *function of [a single, several] variable[s]*
lien entre *x* et *y* ⇔ *link between* x *and* y	
y = f(x)	*y* est [une] fonction de *x* ⇔ y *is a function of* x *y* varie en fonction de *x* ⇔ y *varies as a function of* x *y* dépend de *x* ⇔ y *depends on/upon* x *y* est relié à *x* ⇔ y *is related with/to* x *x* et *y* sont reliés l'un à l'autre ⇔ x *and* y *are interrelated* relation biunivoque, corrélation ⇔ *one-to-one relation, correlation*
x ↗↘ ⇓ y ↗↘	faire varier *x* ⇔ *to make* x *vary (or) to vary* x [quand on fait varier *x*, en faisant varier *x*] on fait varier *y* ⇔ *[when* x *is varied, by varying* x*]* y *is made to vary* la variation de *x* [fait varier *y* , provoque la variation de *y*] ⇔ *the variation of* x *[makes* y *vary, causes* y *to vary]*

	coordonnées ⇔ *coordinates//co-ordinates* cartésiennes, polaires, cylindriques, sphériques ⇔ *Cartesian, polar, cylindrical, spherical* *M* a pour coordonnées *x, y, z* ⇔ M *has coordinates* x, y, z *x* = abscisse ⇔ x-*coordinate (or) abscissa* *y* = ordonnée ⇔ y-*coordinate (or) ordinate* *z* = cote ⇔ z-*coordinate*
	porter *y* en fonction de *x* ⇔ *to plot* y *vs.* x *(ab. of "versus")* report de données ⇔ *data plot* report en coordonnées [*x-y*, logarithmiques] ⇔ x-y *plot, log-log plot*
	*(C)* a pour équation *y = f(x)* ⇔ (C) *has equation* y = f(x) *y = f(x)* est l'équation de *(C)* ⇔ y = f(x) *is the equation for* (C) *M* = point courant ⇔ *general point* faire une représentation graphique de l'équation *y = f(x)* ⇔ *to graph the equation* y = f(x)
	la courbe *(C)*, la surface *(S)* ⇔ *[the] curve* (C), *[the] surface* (S) *(C)*, *(S)* = graphes des fonctions *y = f(x)*, *z = g(x,y)* ⇔ *graphs of the functions* y = f(x), z = g(x,y) [courbe, surface] représentative ⇔ *[2D, 3D] graph*
y′ = dy/dx	dérivée de *y* par rapport à *x* ⇔ *derivative of* y *with respect to* x (ab.) *y* prime = *dy* sur *dx* ⇔ *(ab.)* y *prime* = dy *by* dx *(or)* dy *over* dx *(or)* dy dx