Mathematical Modelling, Sustainability and Management of Natural Resources

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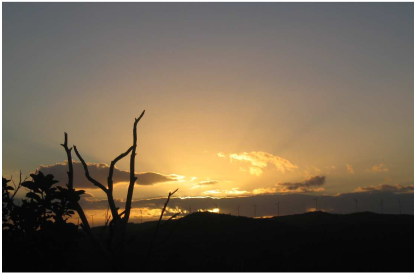
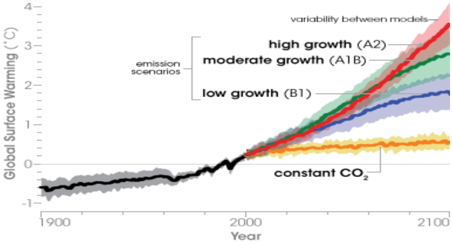
This course deals with issues at the interface nature-society

There is a stake to study the interfaces between nature, economy and society



- Management of exhaustible resources: the energy issue
- Pollution control
  - CO_2 and climate change
  - mitigation and adaptation actions
- Management of renewable resources
  - Fisheries
  - Forests
  - Biodiversity
  - Renewable energy

Global stakes are handled through two international panels: climate change (IPCC) and biodiversity (IPBES)



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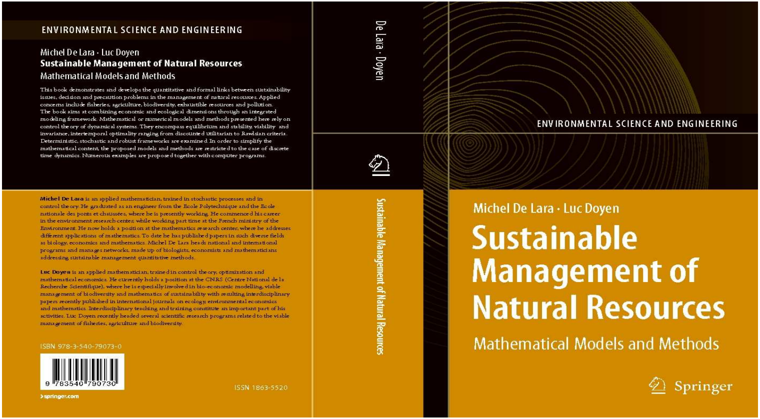
"Nul n'est mieux servi que par soi-même"
"Self-promotion, nobody will do it for you" ;-)

M. De Lara, L. Doyen, Sustainable Management of Natural Resources. Mathematical Models and Methods, *Springer*, 2008

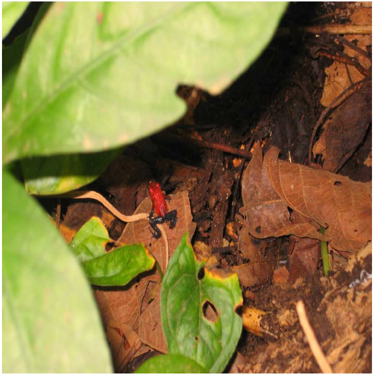


Some references

- CLARK C.W., (1976), *Mathematical Bio-economics. The Optimal Management of Renewable Resources*, J. Wiley & Sons, New York
- CONRAD J. M. (1999), *Resource Economics*, Cambridge University Press
- HEAL G. (1998), *Valuing the Future, Economic Theory and Sustainability*, Columbia University Press, New York
- KOT M., *Elements of Mathematical Ecology* (2001), Cambridge University Press
- WILLIAMS B. K., NICHOLS J.D. & CONROY M.J. (2002), *Analysis and Management of Animal Populations*, Academic Press

Outline of the presentation

Millennium Ecosystem Assessment (2005)

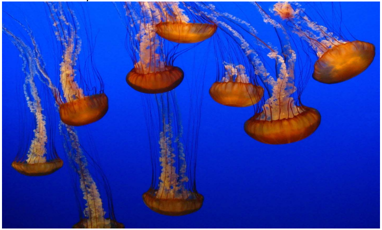


The most important direct drivers of biodiversity loss and ecosystem service changes are

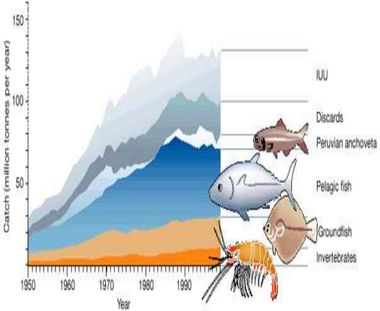
- *habitat change (such as land use changes, physical modification of rivers or water withdrawal from rivers, loss of coral reefs, and damage to sea floors due to trawling)*
- *climate change*
- *invasive alien species*
- *overexploitation*
- *pollution*

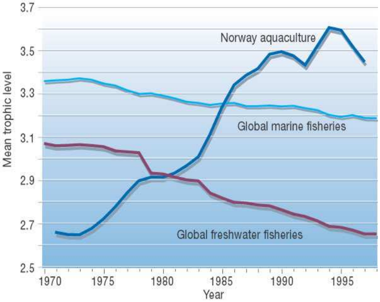
"Fishing Down Marine Food Webs"

Pauly D, Christensen V, Dalsgaard J,
Froese R and Torres F (1998),
Science, 279: 860-863.



“Towards Sustainability In World Fisheries”





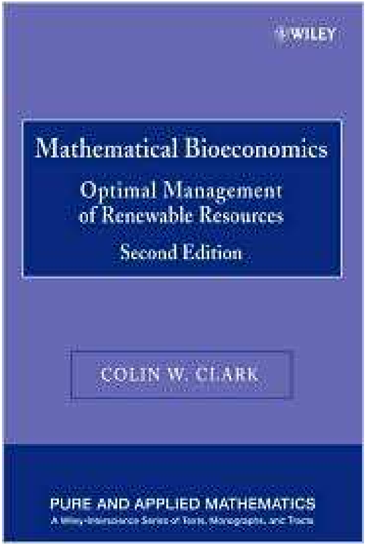
Daniel Pauly, Villy Christensen, Sylvie Guénette, Tony J. Pitcher, U. Rashid Sumaila, Carl J. Walters, R. Watson & Dirk Zeller,
Nature 418, 689-695 (8 August 2002)

Colin W. Clark's *Mathematical Bio-economics* (1976)

> *"Perhaps the most important initial realization for the question of sustainable development is that the overwhelming environmental and resource problems now facing humanity are the result of economically rational individual decisions made every day by each and every one of us"*

CLARK C.W., (1976), *Mathematical Bio-economics. The Optimal Management of Renewable Resources*, J. Wiley & Sons, New York

What is the deep reason why whales have been depleted?



It is economically sensible to deplete the stock of whales

- Imagine that you manage a stock of 1 000 whales.
  How can you exploit them?
- Any "good" whales manager should be a "good" manager, whales or not, and consider the following data on yearly growth rates

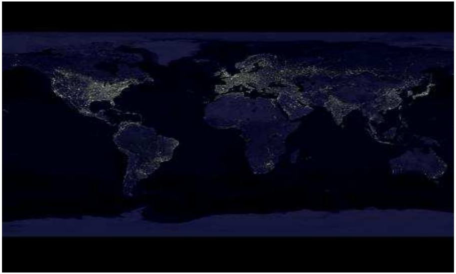
	yearly growth rate
whales	2 — 5%
money	5%

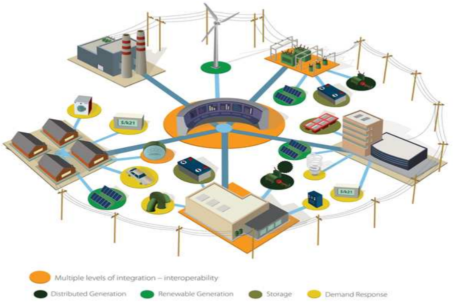
- Any "good" manager should consider at least two management strategies
  - harvest every year the "whales surplus", say 3% of the stocks, and sell it; the population is stationary, and the process can go forever
  - deplete the stock of whales, sell it and invest the money at 5%
- A whales manager would be economically sensible to sell its stocks and to invest this money at a higher rate

Outline of the presentation

Three key drivers are remolding power systems

- Environment
- Markets
- Technology





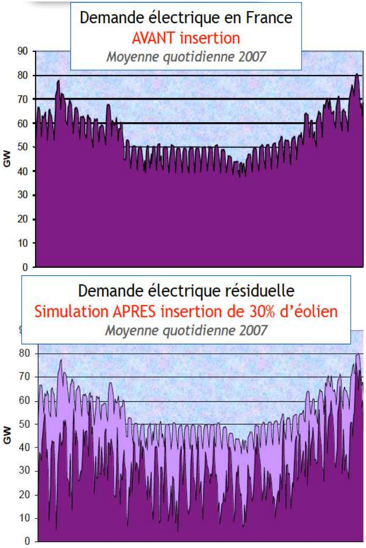
What is "optimization"?

Optimizing is obtaining the best compromise between needs and resources

Marcel Boiteux (président d'honneur d'EDF)

- Resources: portfolio of assets
  - production units
    - costly/not costly: thermal/hydropower
    - stock/flow, predictable/unpredictable: thermal/wind
  - tariffs options, contracts
- Needs: energy, safety, environment
  - energy uses
  - safety, quality, resilience (breakdowns, blackout)
  - environment protection (pollution) and alternative uses (dam water)
- Best compromise: minimize socio-economic costs (including externalities)

Key driver: environmental concern



The European Union climate and energy package materializes an environmental concern with three 20-20-20 objectives for 2020

- a 20% improvement in the EU's energy efficiency
- a 20% reduction in EU greenhouse gas emissions from 1990 levels
- raising the share of EU energy consumption produced from renewable resources to 20%

⇓

Successfully integrating renewable energy sources has become critical, and made especially difficult because they are unpredictable and highly variable, hence triggering the use of local storage

Key driver: economic deregulation

- A power system (generation/transmission/distribution)
  - less and less vertical (deregulation of energy markets)
  - hence with many players with their own goals
- with some new players
  - industry (electric vehicle)
  - regional public authorities (autonomy, efficiency)
- with a network in horizontal expansion
  (the Pan European electricity transmission system counts 10,000 buses, 15,000 power lines, 2,500 transformers, 3,000 generators, 5,000 loads)
- with more and more exchanges (trade of commodities)

$\Downarrow$

A change of paradigm for management
from centralized to more and more decentralized

Key driver: telecommunication technology

Linky

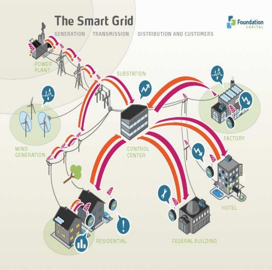
A power system with more and more technology due to evolutions in the fields of metering, computing and telecoms

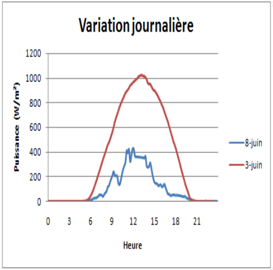
- smart meters
- sensors
- controllers
- grid communication devices. . .

⇓

A huge amount of data which, one day, will be a new potential for optimized management

The "smart grid"? An infrastructure project with promises to be fulfilled by a "smart power system"





- Hardware / infrastructures / smart technologies
  - Renewable energies technologies
  - Smart metering
  - Storage
- Promises
  - Quality, tariffs
  - More safety
  - More renewables (environmentally friendly)
- Software / smart management
  (energy supply being less flexible,
  make the demand more flexible)

smart management, smart operation, smart meter management, smart distributed generation, load management, advanced distribution management systems, active demand management, diffuse effacement, distribution management systems, storage management, smart home, demand side management. . .

Summary

- Three major key factors — environmental concern, deregulation, telecommunication, metering and computing technology — drive the power systems remolding
- This remolding induces a change of paradigm for management: from vertical centralized predictible "stock" energies to more horizontal decentralized unpredictible variable "flow" energies
- Specific optimization skills will be required, because an optimal solution is *balancing on a knife edge*, hence might perform poorly under off-nominal conditions, like a *too much adjusted suit cracking at the first move*

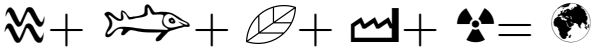
Roger Wets' illuminating example: deterministic vs. robust

of a furniture manufacturer deciding how many dressers of each of 4 types to produce, with carpentry and finishing man-hours as constraints; when the ten parameters become random, the stochastic optimal solution considers all $\approx 10^6$ possibilities and provides a robust solution (257 ; 0 ; 665 ; 34), whereas the deterministic solution $(1,333$; 0 ; 0 ; 67) does not point in the right direction

Outline of the presentation

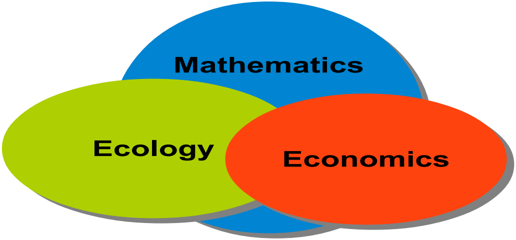
New concepts emerged in the last decades

Rio declaration 1992

- Sustainable development
  - Reconcile ecology-economy
    
  - Intergenerational equity
- Precautionary principle
  Uncertainty not a reason to postpone decisions

The stakes in sustainability can guide the mathematical modelling

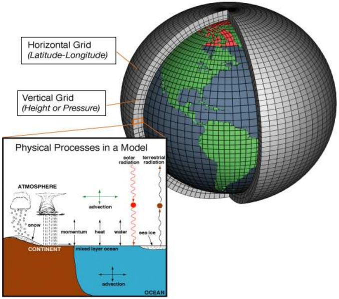
- Quantitative models to evaluate and compare
- Integrated models to facilitate communication between
  - Ecology
  - Socio-economics



- Well-posed models

Applied mathematics: partial differential equations, stochastic processes, statistics, mathematics of decision

We distinguish two polar classes of models: knowledge models *versus* decision models



Knowledge models:
1/1 000 000 → 1/1 000 → 1/1 maps

Office of Oceanic and Atmospheric Research (OAR) climate model

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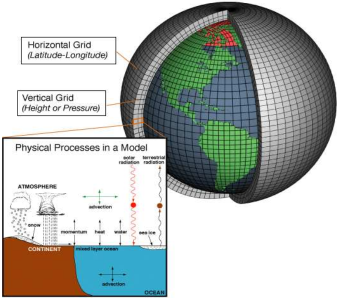

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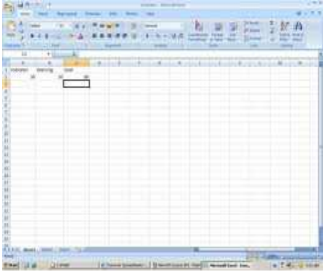


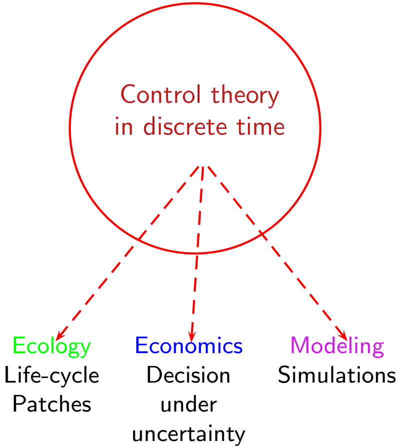
Action/decision models:
economic models are fables designed to provide insight

William Nordhaus economic-climate model

We focus on some specific modelling options for the management of natural resources

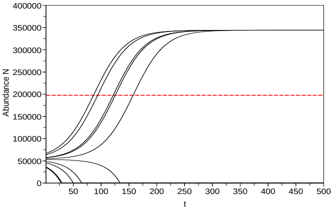
- Take into account
  - Dynamics, nonlinearity, complexity
  - Decisions, actions, controls
  - Uncertainties and information
- Deal with
  - Multi-criteria
    - Ecology: conservation
    - Economy: efficiency
  - Intergenerational equity:
    both short and long term horizon

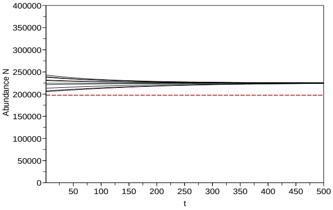
Our main tool is control theory in discrete time



- Problem
  - Find controls/decisions driving a dynamical system to achieve various goals
- Three main ingredients
  - Controlled dynamics
  - Constraints
  - Criterion to optimize

Classes of formal approaches: equilibrium





- Stationary decisions
- Equilibrium and stability approach ⚖
  - Steady state
  - Sustainable yield

Classes of formal approaches: optimality

- Optimal strategies maximizing a criterion
- Intertemporal optimality approach
    - Present value
        - Cost-benefit
        - Cost-effectiveness
    - Maximin criterion (Rawls)
    - Heal-Chichilnisky criterion

Classes of formal approaches: viability

- Viable strategies "satisficing" constraints
- Viability and effectiveness approach
  - PVA: population viability analysis
  - TWA: tolerable windows approach
  - Safe minimum standards
- Viability and invariance theory