Robust Management of a Harvested Ecosystem Model

Esther Regnier & Michel De Lara

Paris School of Economics and University Paris 1 Panthéon-Sorbonne
Ecole des Ponts ParisTech

IIFET 2012
Introduction

The Model

The Deterministic Viability Kernel

The Stochastic Viability Kernel

Conclusion
Introduction

The sustainable management of natural resources must deal with several technical issues:

- **Conflicting objectives**: balancing the risk of resource collapse versus the risk of forgone economic benefits.

- Taking into account the complexity of fisheries dynamics.
  ⇒ Calling for moving toward an ecosystemic approach of fisheries management (WSSD, Johannesburg, 2002).

- Accounting for various sources of **uncertainty**:
  - Stock estimation status.
  - Dynamics of ecosystems.
  - Disturbances: climatic hazard, technical progress, etc.
Motivation

*Emphasizing the importance of taking into account disturbances likely to affect the dynamics of an ecosystem when designing a management strategy.*

- A management strategy is the rule governing the practise of a regulatory instrument.
  **Ex:** Setting the yearly harvest as a fixed fraction of the exploited biomass.

- **Approach:** comparing the set of sustainable initial states (viability kernel) given by a deterministic strategy to that driven by strategies integrating uncertainty.

- **Case-study:** the hake-anchovy couple in the Peruvian up-welling ecosystem.
The Viability Theory

- Seeks the set of states, for which there exist controls, satisfying the dynamics of a system, and constraints, describing given objectives, at the same time (J. P. Aubin, 1991).

- Identifies a decisions sequence capable of maintaining the system viable. Decisions (controls) are computed by use of a dynamic programming equation.

- All constraints must be satisfied at all dates. The approach can be softened by accepting constraint violations with low probability in the stochastic case.
Introduction

The Model

The Deterministic Viability Kernel

The Stochastic Viability Kernel

Conclusion
Generic ecosystem model

- We consider a two-dimensional state model

\[
\begin{align*}
  y(t+1) &= y(t)R_y(y(t), z(t))(1 - v(t)) \\
  z(t+1) &= z(t)R_z(y(t), z(t))(1 - w(t))
\end{align*}
\]

- state vector \((y, z)\) represents biomasses,
- control vector \((v, w)\) is fishing effort of each species, each lying in \([0, 1]\)
- \(R_y\) and \(R_z\) are annual growth factors.
- catches are \(vyR_y(y, z)\) and \(wzR_z(y)\) (measured in biomass)
Introduction

The Model

The Deterministic Viability Kernel

The Stochastic Viability Kernel

Conclusion
The Viability Kernel

The viability kernel is the set of initial states $y(t_0), z(t_0)$ from which there exists, for $t = t_0, \ldots, T$, controls $v(t), w(t)$ producing a trajectory $y(t), z(t)$ such that a priori conflicting requirements

- **preservation** (minimal biomass thresholds): $y(t) \geq y^b, z(t) \geq z^b$

- **economic/social requirements** (minimal catch thresholds): $\begin{align*}
  v(t)y(t)R_y(y(t), z(t)) & \geq Y^b, \\
  w(t)z(t)R_z(y(t), z(t)) & \geq Z^b
\end{align*}$

are satisfied for $t = t_0, \ldots, T$. 
The Viability Kernel

- If the thresholds \( y^b, z^b, Y^b, Z^b \) are such that the following expressions are satisfied

\[
y^b R_y(y^b, z^b) - Y^b \geq y^b \quad \text{and} \quad z^b R_z(y^b, z^b) - Z^b \geq z^b
\]

- the viability kernel is

\[
\mathbb{V}(t_0) = \{ (y, z) \mid y \geq y^b, z \geq z^b, \\
y R_y(y, z) - Y^b \geq y^b, z R_z(y, z) - Z^b \geq z^b \}
\]
The Peruvian hake-anchovy system

- Fitted by a discrete-time Lotka-Volterra system with density-dependence (IMARPE):

\[
\begin{align*}
R_y(y(t), z(t)) \\
&= y(t) \left( R - \frac{R}{\kappa} y(t) - \alpha z(t) \right) (1 - v(t)) \\
& \quad \text{Viability Kernel:} \\
&= z(t) \left( L + \beta y(t) \right) (1 - w(t)) \\
& \quad \text{Viability Kernel:}
\end{align*}
\]

- \( y \) prey biomass: anchovy
- \( z \) predator biomass: hake

- The associated viability kernel

\[
\mathbb{V}(t_0) = \left\{ (y, z) \mid y \geq y^b, z^b \leq z \leq \frac{1}{\alpha} \left[ R - \frac{R}{\kappa} y - \frac{y^b + Y^b}{y} \right] \right\}.
\]
Introduction

The Model

The Deterministic Viability Kernel

The Stochastic Viability Kernel

Conclusion

The Viability Kernel

The annual objectives and calibration were set by IMARPE (taller internacional sobre la anchoveta peruana), based on data from 1971 to 1981:

Figure: Viability Kernel for minimal biomass thresholds $y^b = 7000$ kt (Anchovy) and $z^b = 200$ kt (hake), and the minimal catches thresholds $Y^b = 2000$ kt (Anchovy) and $Z^b = 5$ kt (hake).
Robust Management of a Harvested Ecosystem Model

E. Regnier & M. De Lara

Introduction

The Model

The Deterministic Viability Kernel

The Stochastic Viability Kernel

Conclusion
Accounting for uncertainty

Figure: Observed and Simulated biomasses over 1971-1981

(a) Anchovy

(b) Hake
Ecosystem model with uncertainty

- In the stochastic approach the model becomes:

\[
\begin{align*}
    y(t + 1) &= y(t) \left( R - \frac{R}{\kappa} y(t) - \alpha z(t) \right) (1 - v(t)) + \varepsilon_y(t) \\
    z(t + 1) &= z(t) \left( L + \beta y(t) \right) (1 - w(t)) + \varepsilon_z(t)
\end{align*}
\]

where \( \varepsilon_y(t) \) and \( \varepsilon_z(t) \) are additive disturbance terms.

- The targeted preservation and economic objectives are kept equal.
The uncertainties space $S$

- Defined by taking the difference between observed and simulated biomasses
  \[ \varepsilon_y(t) = y(t) - \hat{y}(t); \quad \varepsilon_z(t) = z(t) - \hat{z}(t). \]

Figure: $(\varepsilon_y(t), \varepsilon_z(t))$ over 1971-1981
The Stochastic Viability approach

- $S = [\varepsilon_{y}^{\text{min}}, \varepsilon_{y}^{\text{max}}] \times [\varepsilon_{z}^{\text{min}}, \varepsilon_{z}^{\text{max}}]$

- An uncertainty scenario is $(\varepsilon_{y}(\cdot), \varepsilon_{z}(\cdot)) = ((\varepsilon_{y}(t_{0}), \varepsilon_{z}(t_{0})), \ldots, (\varepsilon_{y}(T), \varepsilon_{z}(T)))$

- The set of uncertainty scenarios is $\Omega = S^{T-t_{0}+1}$.

- $\Omega$ is equipped with probability distribution.

- We adopt the uniform distribution law to simulate scenarios over $S$ (of course results will be conditioned by this choice).
The Stochastic Viability approach

- The stochastic viability kernel of confidence level $\beta$ is the set of initial states $y(t_0), z(t_0)$ from which there exists, for $t = t_0, \ldots, T$, controls $v(t), w(t)$ producing a trajectory $y(t), z(t)$ such that over all scenarios

- minimal biomass thresholds:

  \[ y(t) \geq y^b, z(t) \geq z^b \]

- minimal catch thresholds:

  \[ v(t)y(t)R_y(y(t), z(t)) \geq Y^b, \]
  \[ w(t)z(t)R_z(y(t), z(t)) \geq Z^b \]

are satisfied for $t = t_0, \ldots, T$ with a probability $\geq \beta$. 
The Stochastic Viability Kernel

Figure: Viability Probability level curves
Robust Management of a Harvested Ecosystem Model

E. Regnier & M. De Lara

Introduction

The Model

The Deterministic Viability Kernel

The Stochastic Viability Kernel

Conclusion
Conclusion

- There are no robust viability kernel (100% probability)

- The set of initial states included in the deterministic viability kernel are viable with a probability of about 70%

- We have developed a tool capable of attaching to a potential initial state, a probability of achieving conflicting objectives

- For a given confidence level, the approach provides a corresponding control sequence