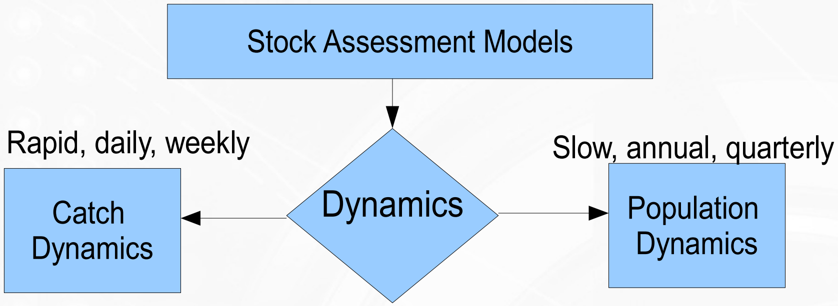
Catch Dynamics Stock Assessment Models for Data-Moderate Fisheries

Catch Dynamics Models



$$\frac{dC}{dt}=f(E,N)$$

Fishing enters directly through nominal fishing effort at high frequency

Catch rate is the result of one observed predictor (effort) and one latent predictor (abundance)

Solutions lead to **fishing operational stock assessment models**

$$f(E,N)=qEN$$

$$\frac{dC}{dt}=f(F,N)$$

Fishing enters indirectly through its effect on fish survival at the scale of fish population dynamics (annual, quarter)

Catch rate is the result of two latent predictors (fish mortality and abundance)

Solutions lead to **population dynamics stock assessment models**

$$f(F,N)=FN$$

- Population dynamics stock assessment models are vastly predominant.
- Nominal effort is mostly used to fit catch rate models to generate annual indexes of fish abundance

Why, given that nominal effort is the single observed cause of catch?

- Fish population dynamics is sexier than fishing operational dynamics
- Fish population dynamics creates more jobs
- In textbooks stock assessment is synonym with fish population dynamics (e.g. Quinn-Deriso)
- Founders such as Baranov, Beverton, Holt, Ricker, were biologists?

Catch Dynamics Models

$$\frac{dC}{dt}=f(E,N)$$

$$f(E,N)=qEN$$

$$C(t)=q\int E(t)N(t)dt=qE(t)\int_0^t\left(N_0e^{-Mt}-\int_0^{t-\delta t}C(\tau)e^{-M(t-\delta t)}d\tau\right)dt$$

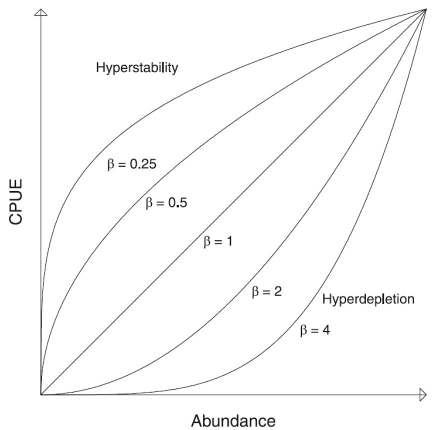
Switching to discrete time steps

$$C_t=qE_tN_te^{-M/2}=qE_t\left(N_0e^{-Mt}-e^{-M/2}\sum_{i<t}C_ie^{-(t-i-1)M}\right)e^{-M/2}$$

This is Leslie-Davies-Chapman depletion model used to do stock assessment of some squid stocks and stocks that are data-poor

Catch Dynamics Models – Process Model

Fig. 1. Relationship between CPUE and abundance based on different values of the shape parameter β.



Harley, Myers,. Dunn
CJFAS 58:1761, 2001

$$C = q \cdot f \cdot N;$$

$$q = \alpha f^{\lambda} N^{\beta};$$

$$C = \alpha f^{(1+\lambda)} N^{(1+\beta)}.$$

Bannerot, Austin
TAFS 112:608, 1983

Enter hyperstability/hyperdepletion, let's call it "abundance response"

$$\frac{C_t}{E_t} = k N_t^{\beta} e^{-M/2} = k \left(N_0 e^{-Mt} - e^{-M/2} \sum_{i=1}^{t-1} C_i e^{-M(t-i-1)} \right)^{\beta} e^{-M/2}$$

Enter gear saturability/synergy, let's call it "effort response"

$$C_t = k E_t^{\alpha} N_t^{\beta} e^{-M/2} = k E_t \left(N_0 e^{-Mt} - e^{-M/2} \sum_{i=1}^{t-1} C_i e^{-M(t-i-1)} \right)^{\beta} e^{-M/2}$$

Relax the depletion assumption, allow for replenishment

$$C_t = k E_t^{\alpha} N_t^{\beta} e^{-M/2} = k E_t^{\alpha} \left(N_0 e^{-Mt} + \sum_{i=1}^{t} P_i e^{-M(t-i)} - e^{-M/2} \sum_{i=1}^{t-1} C_i e^{-M(t-i-1)} \right)^{\beta} e^{-M/2}$$

$$t > 0, C_t \geq 0, E_t \geq 0, k > 0, N_0 > 0, \alpha > 0, \beta > 0, M > 0, -N_0 e^{-M} \leq P_i \leq +\infty$$

Catch Dynamics Models – Observation Model

$$C_t = k\,E_t^{\alpha} N_t^{\beta} e^{-M/2} = k\,E_t^{\alpha}\left(N_0 e^{-Mt} + \sum_{i=1}^{t} P_i e^{-M(t-i)} - e^{-M/2}\sum_{i=1}^{t-1} C_i e^{-M(t-i-1)}\right)^{\beta} e^{-M/2},$$

$$t>0, C_t \geq 0, E_t \geq 0, k>0, N_0>0, \alpha>0, \beta>0, M>0, -N_0 e^{-M} \leq P_i \leq +\infty$$

$$\chi_t = C_t + \varepsilon_t \qquad \textit{Additive}$$

$$\chi_t = C_t e^{\varepsilon_t} \qquad \textit{Multiplicative}$$

$$\varepsilon_t \sim \textit{Normal}\left(0, \sigma^2\right)$$

The catch of one fleet at one time step is the result of two causes:

- Nominal effort (E)
- Stock abundance (N_0, $\{P_i\}$),

and five constants,

- A scaling parameter (k),
- An effort response parameter (α),
- An abundance response parameter (β),
- A natural mortality parameter (M),
- A stochastic response parameter (σ^2)

Catch Dynamics Models

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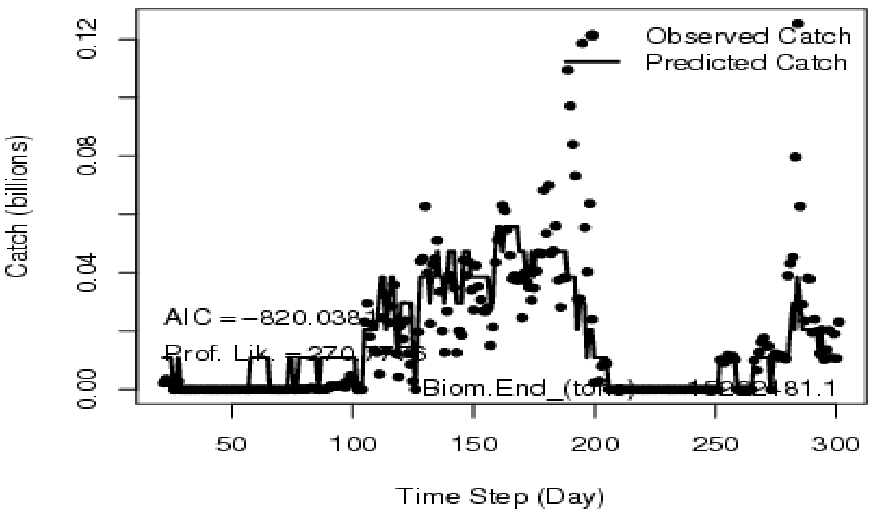
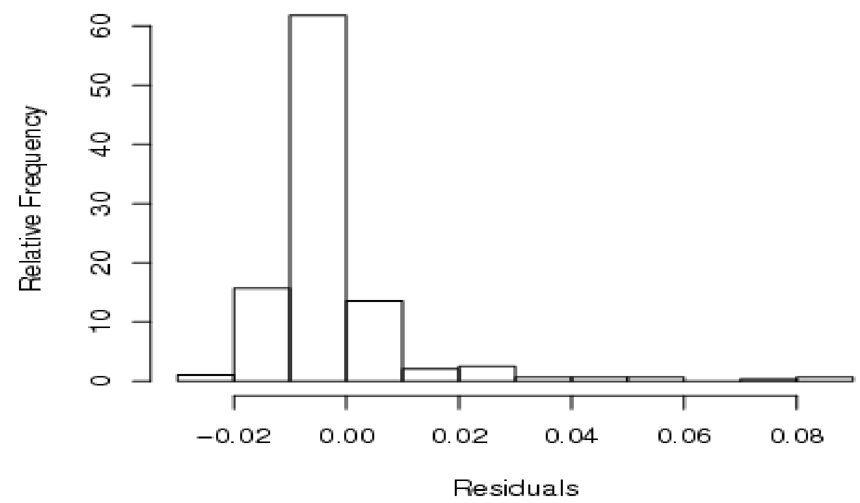
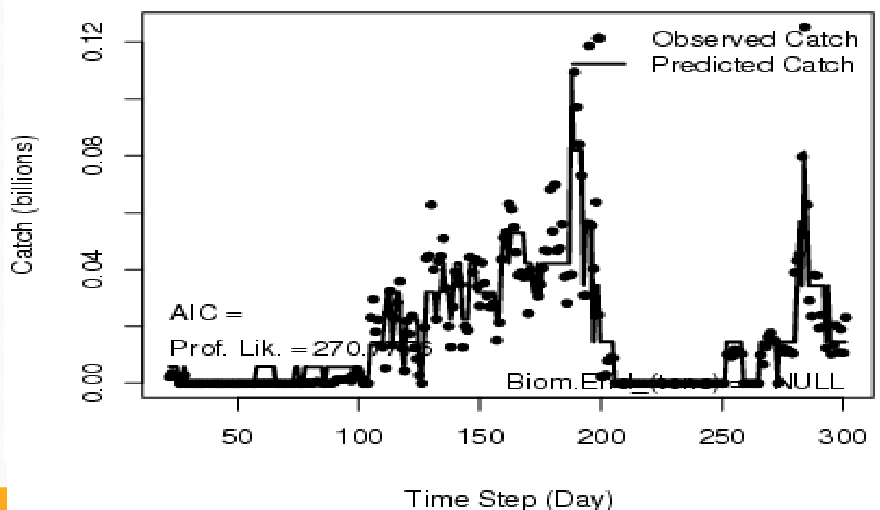
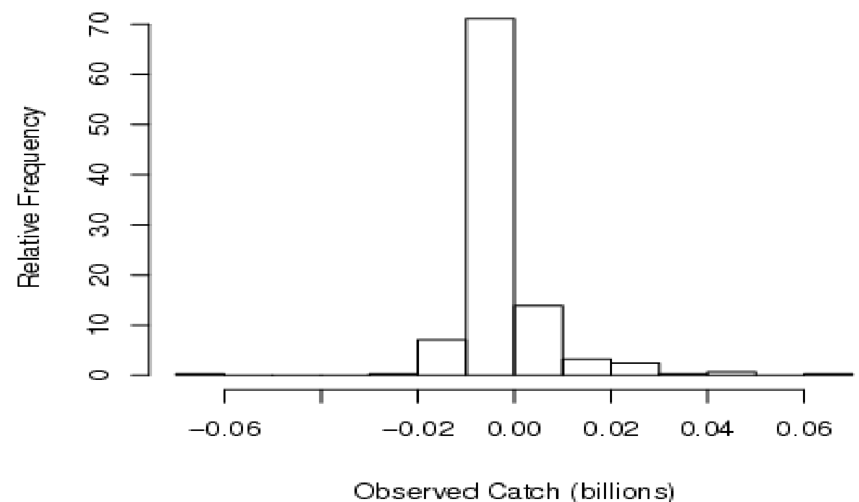
Pure Depletion AIC=-820 One Perturbation at Day 189=-999









Catch Dynamics Models

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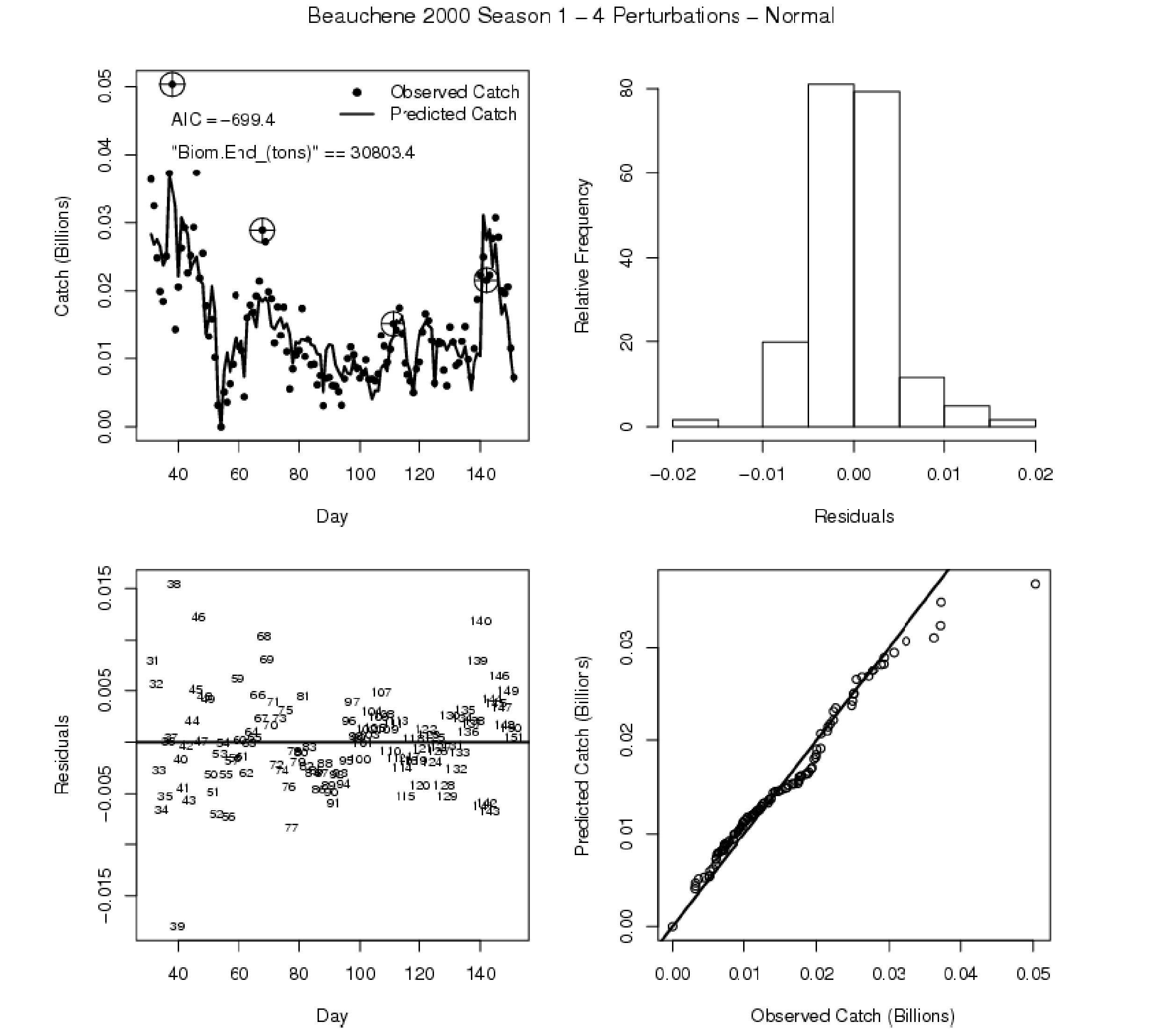
2000 Loligo summer season in the Falklands: a case of 4-perturbations



Catch Dynamics Models

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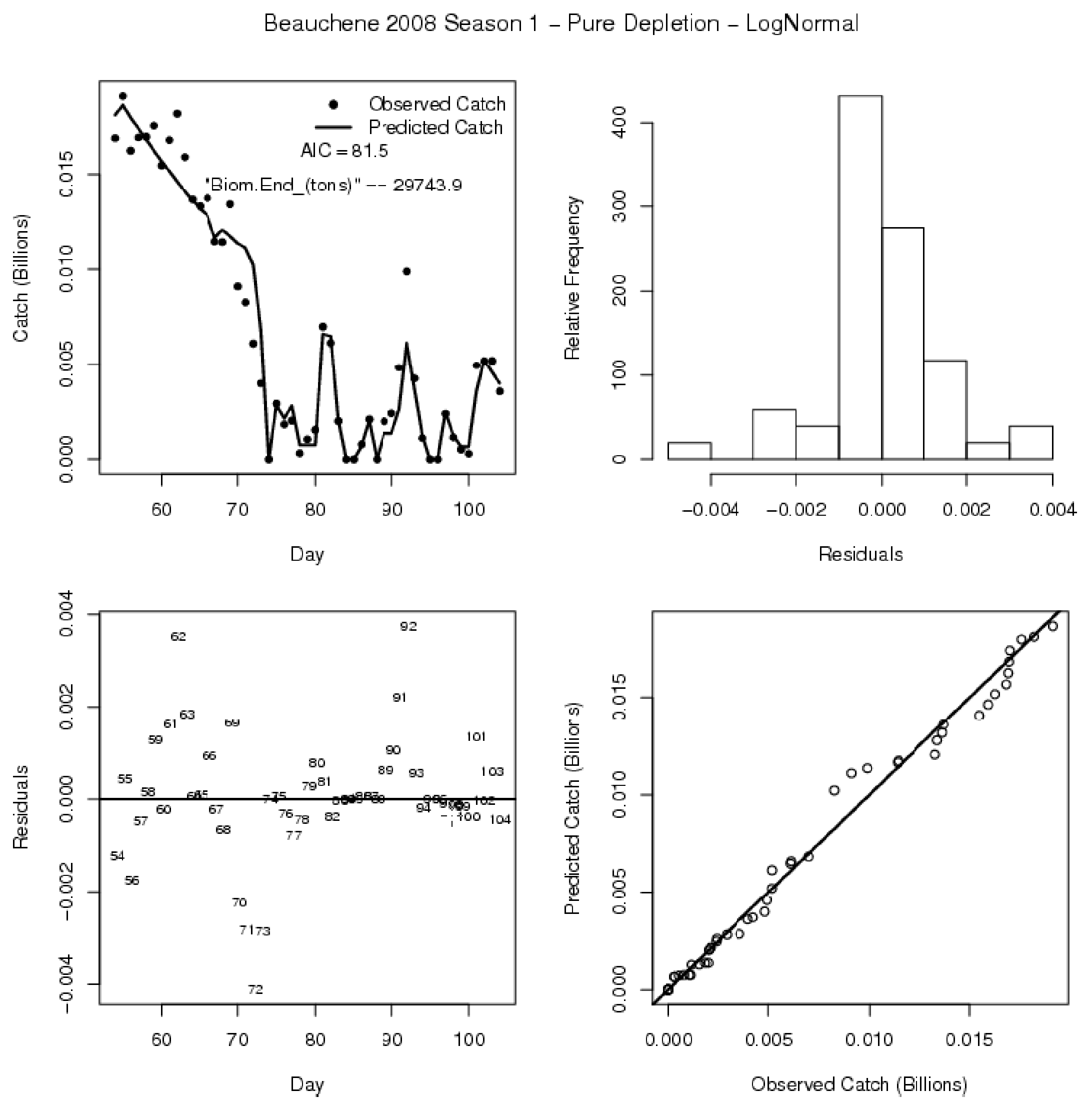
2008 Loligo summer season in the Falklands: a case of 0-perturbations, pure depletion



Catch Dynamics Models

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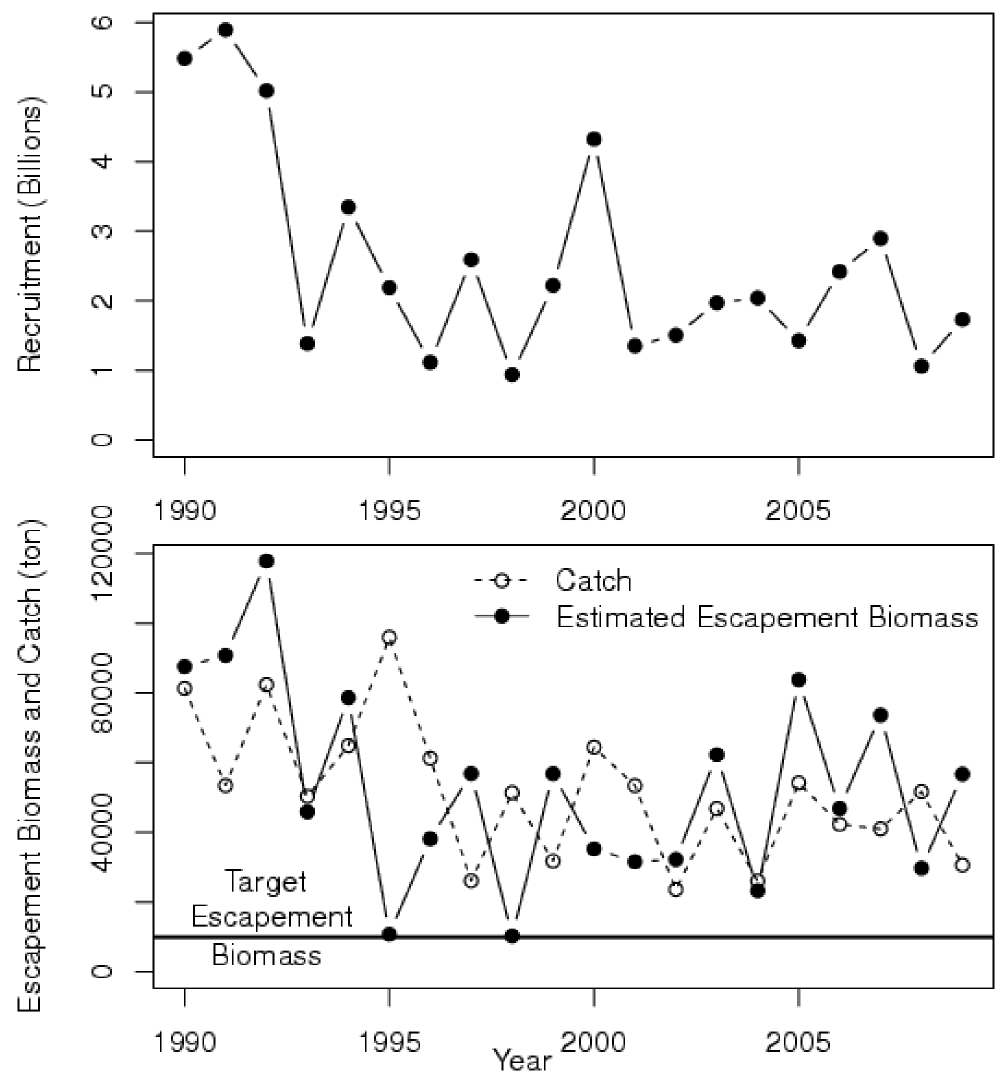
Real-time management to achieve a target



Catch Dynamics Models

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	Populations Dynamics Models	Catch Dynamics Models
Data aggregation	Data aggregated annually/quarterly to scale it to fish populations dynamics	Data aggregated daily or weekly because the fishing operation has a fast dynamics
Biological comprehensiveness	Very comprehensive from the fish point of view, allows estimation of fish abundance and productivity	Limited, only allows estimation of fish abundance, but not productivity.
Fishery comprehensiveness	Quite comprehensive, allows estimation of gear selectivity, catchability.	Quite comprehensive, allows estimation of gear catchability, saturability.
Cost	Very expensive, requires armies of biologists measuring fish, counting rings in bones, carrying out surveys.	Very cheap, requires observers at sea or at ports armed just with a ruler and scales.
Reaction time	Slow, the status of the stock is estimated for years past, and management measures come two or more years after the stock is estimated at risk	Fast, the stock abundance status is realized for the current season and management measures can be implemented for the current season.
Implementation of management advice	Difficult, because of their slow dynamics (the dynamics of the fish population) management tend to be framed in terms of annual TAC, but catch limits are difficult to enforce	Easy, because these models at their rapid dynamics return estimates of stock status in real time so management can be based on effort limits.
Statistical underpinnings	Integrated likelihood/Bayesianity, observed catch at age, catch at length, indices are caused by several population and fisheries processes.	Nonlinear regression/recursive models, observed catch is caused by observed fishermen effort and latent fish abundance.

Catch Dynamics Models

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'Data' →

Biomass	Season	Catch
B0_1	1	C_1
B0_2	2	C_2
...	...	...
B0_S	S	C_S

Biomass Dynamics Model →

$$B(s)=B(s-1)+rB(s-1)\left(1-\left(\frac{B(s-1)}{K}\right)^{p}\right)-C(s-1),\ s=1,\dots,S$$

Hierarchical Likelihood Model →

$$l(r,K,p;\{B_s\})=-\frac{1}{2}\sum_{s=1}^{S}\log(\hat{\sigma}^2_{B(s)})-\frac{\sum_{s=1}^{S}(\log(\hat{B}(s))-\log(\hat{\hat{B}}(s)))^2}{2\hat{\sigma}^2_{\hat{B}(s)}}$$

$$\hat{v}(\hat{MSY})=\begin{bmatrix}\frac{\partial MSY}{\partial r} & \frac{\partial MSY}{\partial K}\end{bmatrix}\begin{bmatrix}\hat{v}(\hat{r}) & cov(\hat{r},\hat{K})\\ cov(\hat{K},\hat{r}) & \hat{v}(\hat{K})\end{bmatrix}\begin{bmatrix}\frac{\partial MSY}{\partial r}\\ \frac{\partial MSY}{\partial K}\end{bmatrix}$$

Catch Dynamics Models

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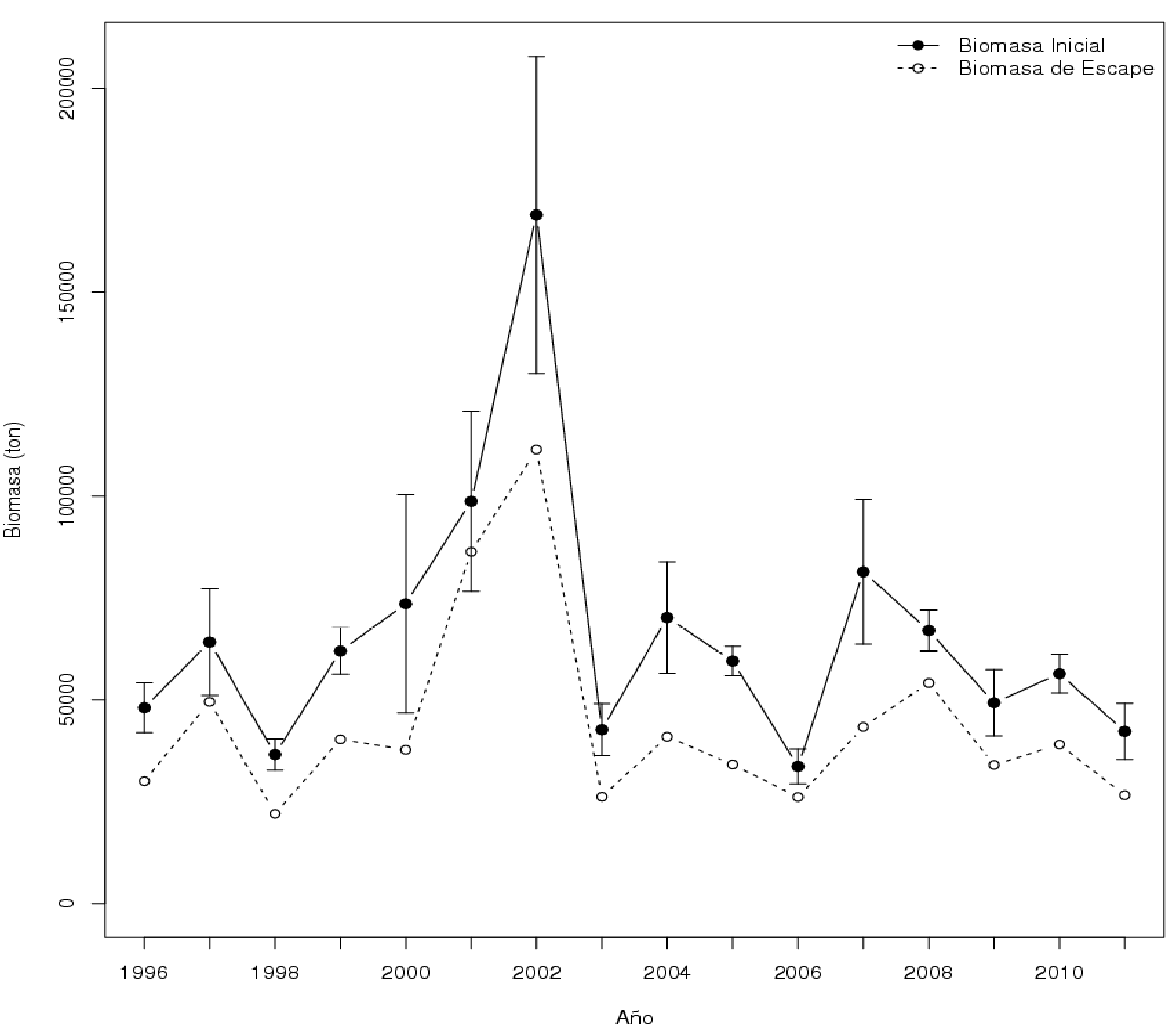

Sea urchin
Fishery
In
Southern
Chile

Catch Dynamics Models

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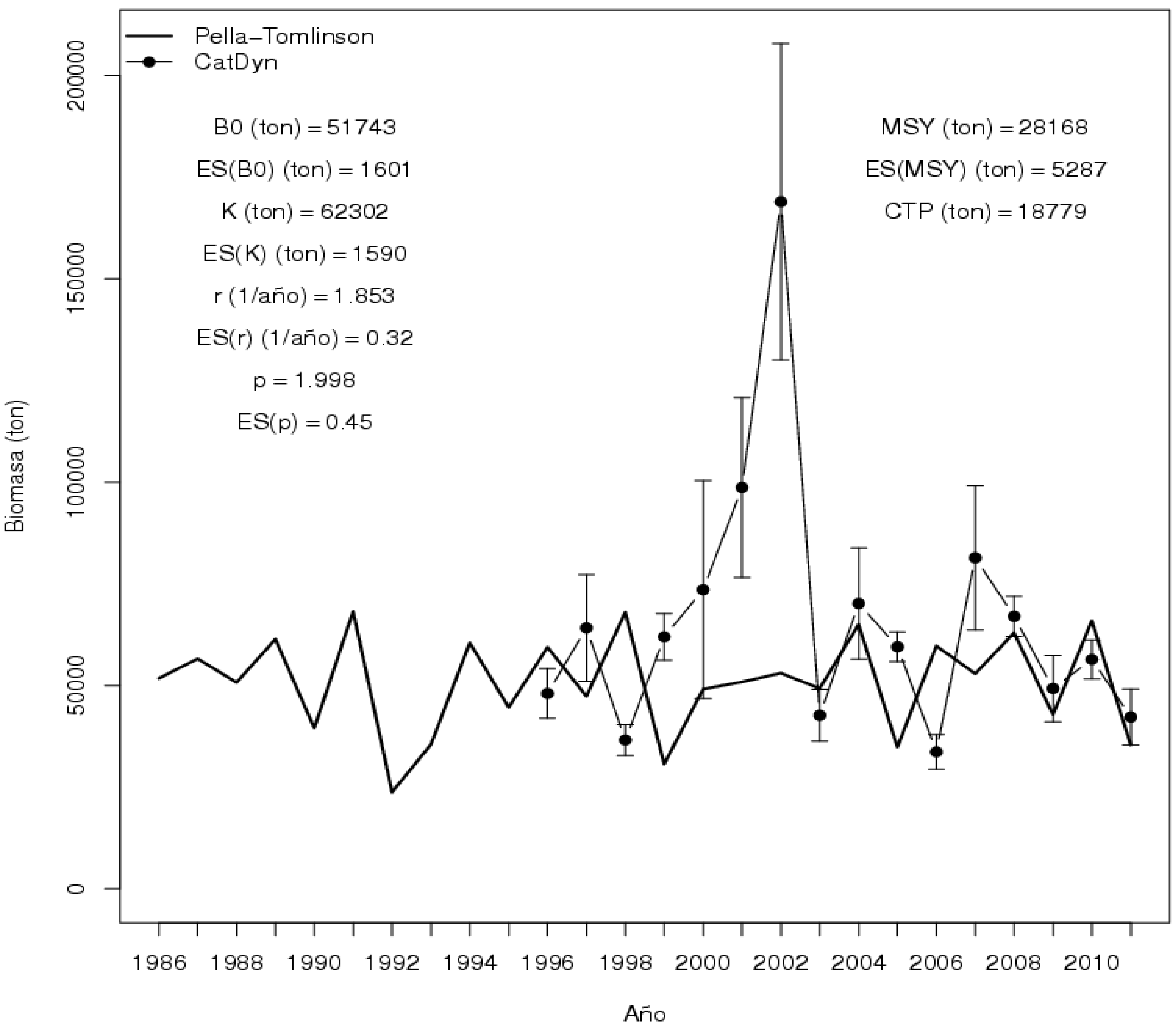

Sea urchin Fishery In Southern Chile

Implementation of catch dynamics models

- CatDyn is an R package available from CRAN that allow estimation of CDMs with 0, 1, …, 4 perturbations, additive or multiplicative observation error, estimated or fixed natural Mortality.
- The basic data needed is high-frequency (daily or weekly) time series of paired observations of catch in numbers and nominal effort in a measure that is approximately exact.
- If the catch is recorded in biomass, then the basic data must also have a matching vector of mean bodymass per time step

Catch Dynamics Models

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Way ahead/work in progress:

- Write down the multi-fleet version of the model
- Write down the functions to fit the multi-annual production models to estimate productivity/MSY.
- Set up simulations to test the models under perfect conditions and under conditions where assumptions are violated
- Write the models in ADMB to speed up and secure convergence
- Create a GUI to control the package from R, using PBSmodelling and PBSadmb
- Apply the model to the following list of stocks:
  - Redfish fished by a Spanish fleet in the North Sea
  - Blue ling fished by an Icelandic fleet in Iceland EEZ
  - Hake fished by two fleets in central Chile
  - Squid fished by three fleets on the Eastern coast of the USA
  - Shrimps and finfish in the Persian Gulf

Catch Dynamics Models

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Set up a spatially distributed stock with RandomFields ← Nuclei may move or stay put; nuclei will decay Because of natural mortality

Harvest the stock by a group of agents over a period of time ← Agents will differ in efficiency or will be Identical; error will be additive or multiplicative

Introduce random pulses of abundance increase during the harvest period ← Pulses will be caused by recruitment or agents expanding area of opearation

Observe the harvest process in a perfect manner or incompletely ← Effort will be an exact predictor or a random variable, raised or not

Estimate abundance and fishing operational parameters with catdyn ← Counting the right number of perturbations or missing a few

Calculate bias, variance, mean square Error over many iterations