

# Economically optimal management strategies for the South Georgia Patagonian toothfish fishery

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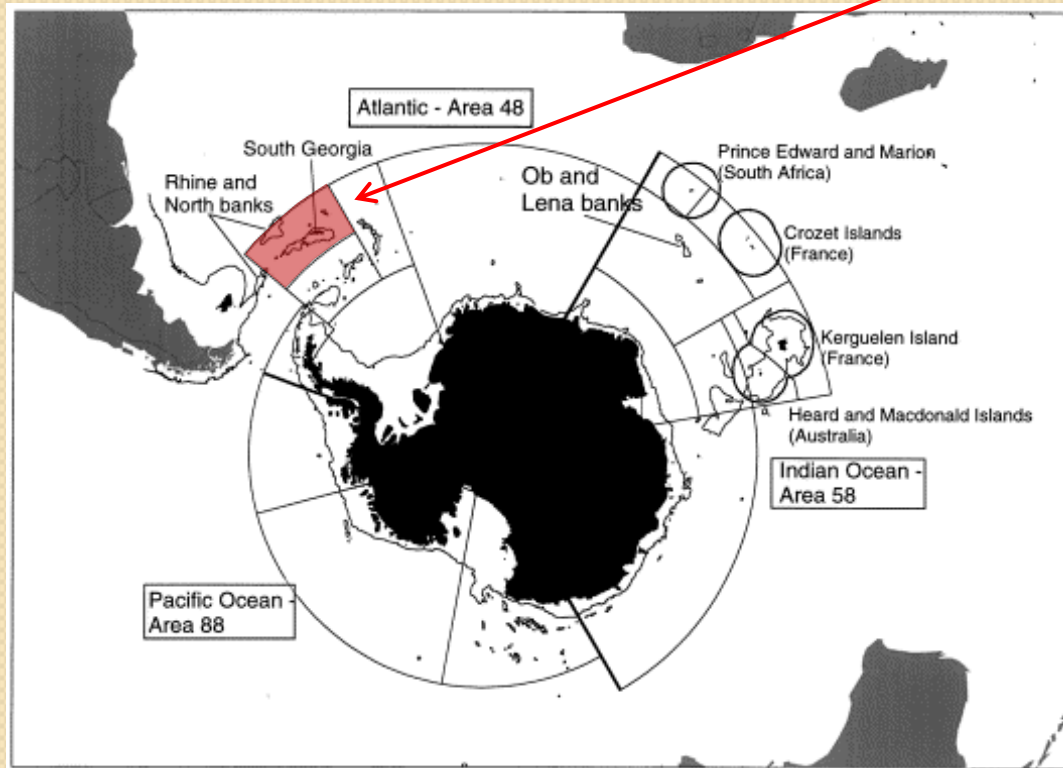
# Patagonian toothfish

## *Dissostichus eleginoides*



- Known as Chilean sea bass, mero, black hake, black cod, sable fish etc.
- Large demersal, long-lived fish (up to 2.2m, 100kg, 50 years old).
- Live in depths 200-2000m around islands in the Southern Ocean and Antarctic continent
- Luxury seafood with main markets in USA, Japan and EU
- Global catch peaked in mid-1990s (40,000 t declared, with roughly 40,000 t of IUU), declined to 24,000 t in 2008

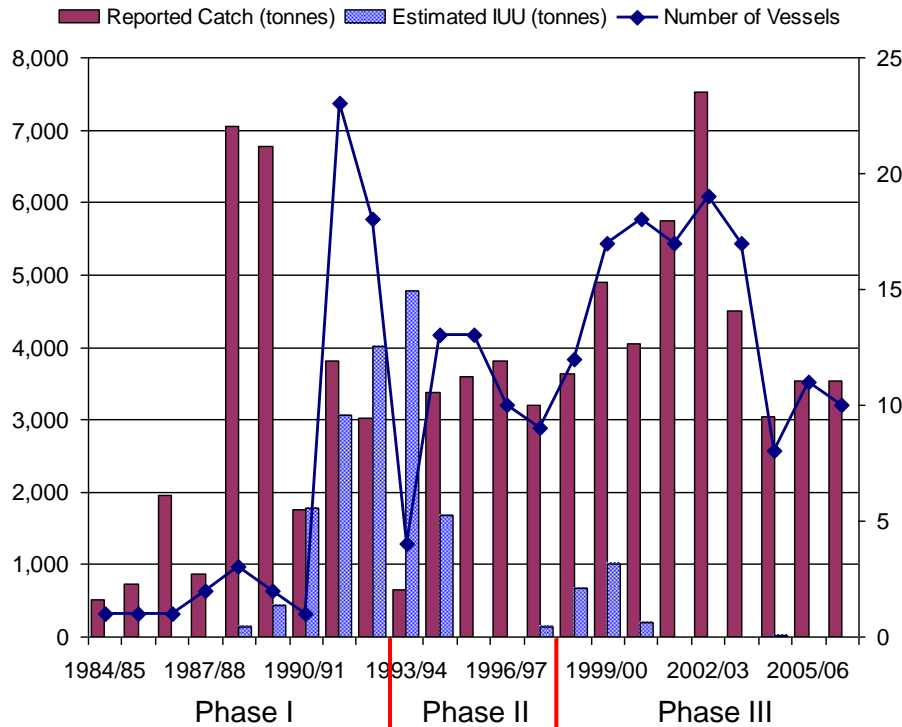
# Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Subarea 48.3



Map of Convention Area (Antarctic Treaty)

**Management measures implemented by the Government of South Georgia and South Sandwich Island (GSGSI) within its Maritime Zone**

# Development of the Fishery (3 phases)



**Historical catches of toothfish in Subarea 48.3**  
Source: SC-CAMLR (2007).

**Phase I**

Commercial fishery began in 1985

Exploratory fishery

Conservation measures for seabirds 1993-

**Phase II**

Combating IUU (e.g. observers, FPV)

Precautionary harvest control rules (HCRs) 1995-

**Phase III**

Fully developed fishery 1997- present

# Precautionary HCRs

- Designed to avoid long-term adverse impacts on the stock and ecosystem.
- Use probabilities of meeting pre-defined rules in a fixed period (=35 yrs, 1 generation time)
  - Probability that spawning stock fall below 20% of virgin level over 35 yrs  $\leq 0.1$
  - Probability that spawning stock  $\geq 50\%$  of virgin level at the end of the period  $\geq 0.5$
  - TAC is the maximum value that satisfies both
- Biological and ecological conservation-oriented.
- No consideration given to economic aspects.

# Objectives

- Explore alternative set of potential management strategies (MSs) with economic considerations.
- Compare MSs based on both economics and biological performance criteria

# Approach

- Demonstrate how MEY-based policies can be implemented in practice.
- Translating the complex Bayesian age-structured integrated assessment model to a simple biomass dynamic model, while preserving key life history characteristics.
- Test the future performance of the current versus alternative management strategies using a simulation-based Management Strategy Evaluation (MSE) framework.
- Few MSE exist that explicitly include economics

# Constructing bioeconomic operating model (OM)

- OM – mathematical representation of the “true” dynamics - key component of MSE
- Simulation-based, flexible framework
- Used to
  1. calculate economically optimal harvesting policies;
  2. simulate the impacts of candidate MSs on the status of the stock, and profitability.

# Population dynamics

- Simple biomass dynamic model
- Key life history parameters and their distribution obtained from the assessment model

$$B_{t+1} = B_t + rB_t(1 - B_t / K) - Y_t \quad (1)$$

$$\sum_{j=0}^{\infty} e^{-rj} l_j m_j w_j a = 1 \quad (2)$$

$B_t$  = biomass at time  $t$

$Y_t$  = harvest at time  $t$

$r$  = intrinsic growth rate

$K$  = carrying capacity

$l_j$  = probability of surviving to age  $j$

$m_j$  = maturity at age  $j$

$w_j$  = weight at age  $j$

$a$  = recruit per unit of SSB

(1) Logistic growth function; (2) Euler-Lotka equation (Euler 1907; Myers et al 2007)

# Parameter estimates

- Estimating  $r, K$

- “One-way trip” time series data
- Obtained 1000 Monte Carlo sample of  $r$  using the known distributions of the key life history parameters
- $K$  = the biomass at 1985,  $B_{2007} = 0.55K$
- Obtained a distribution of plausible values of  $K$  given the values of  $r$ , that gives  $B_{2007} = 0.55K$ , subject to (1)

- Estimating catchability coefficient  $q$

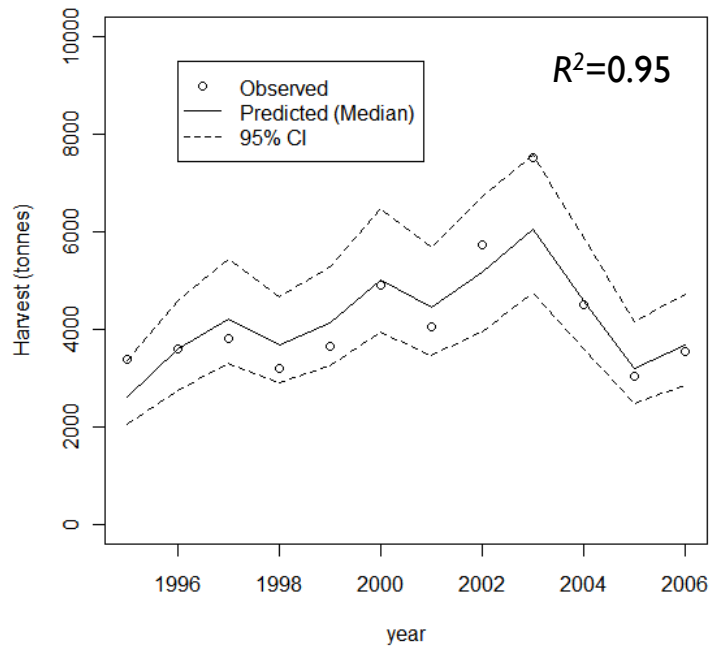
- Empirically estimated from data (1997-2007). Effort ( $E_t$ )= number of hooks

$$Y_t = qE_t B_t \quad (3)$$

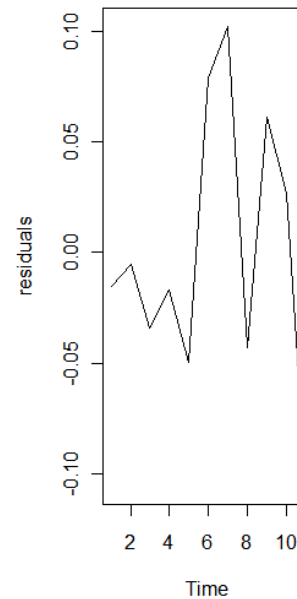
End result is 1,000 covariant samples of the key parameter vector  $(r, K, q)$

# Fits of the production function to data (1997-2007)

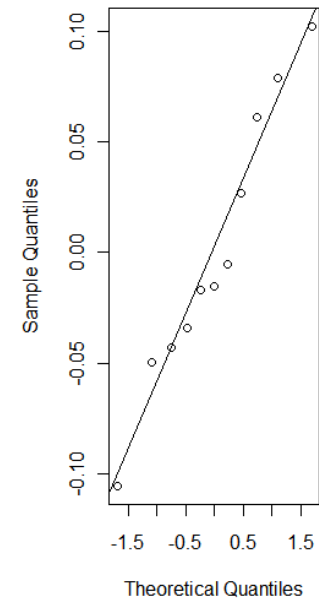
## Predicted vs observed harvest



## Residual Plot



## Normal Q-Q Plot



# Optimal harvesting policy

$$\text{Maximize } NPV = \sum_{t=0}^{\infty} \left( \frac{1}{1+\delta} \right)^t \pi(B_t, Y_t) \quad (4)$$

$$\pi(B_t, Y_t) = pqE_t B_t - c_v E_t - c_f V \quad (5)$$

Subject to Eq(1) and  $B_t, Y_t \geq 0$

$\delta$  = Discount rate

$p$  = Price of fish ( $P_{2007}$  10%)

$C_v$  = Variable cost ( $C_{v2007}$  15%)

$C_f$  = Fixed cost

$V$  = Number of vessel

# Estimates of optimal conditions

		$\delta=0.01$			$\delta=0.02$		
		Median	95% CI		Median	95% CI	
B*	tonnes	66,692	54,792	78,468	64,190	53,163	75,170
E*	m. hooks	11.66	9.86	13.26	12.29	10.58	13.86
Y*	tonnes	3,143	2,644	3,590	3,197	2,699	3,641
		$\delta=0.03$			$\delta=0.04$		
		Median	95% CI		Median	95% CI	
B*	tonnes	61,702	51,302	71,458	59,459	50,299	69,007
E*	m. hooks	12.97	11.17	14.47	13.59	11.91	14.96
Y*	tonnes	3,236	2,732	3,689	3,266	2,747	3,713

CCAMLR's target biomass(0.5K)=54,000 tonnes

$E_{2007} = 15.7$  million hooks

$Y_{2007} = 3,600$  tonnes,  $Y_{2008} = 3,900$  tonnes

# Validation of the model as a management tool

- Is the reduced model able to replicate the management action (TAC) as the full-assessment model?
  - 3,478 tonnes (reduced model)
  - 3,554 tonnes in 2006 (full-assessment model)
  - 2% difference

# Alternative effort-base MSs

(I) Constant effort strategy, maintaining effort level at  $E^*$  .

- $E^* = 12.3$  million hooks ( $\delta=0.02$ , median) as a baseline:
  - Strong conservation objectives
  - Society sees Antarctic as a sanctuary
  - Avoid extinction risks
- Immediate effort reduction from  $E_{2007}$  to  $E^*$   
**In practice, it may be difficult to implement**

## (2) Gradual effort reduction schemes

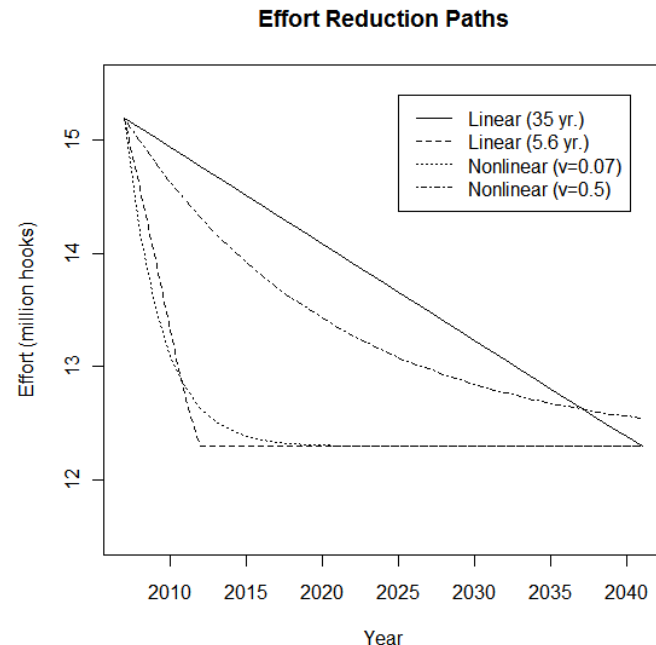
Reduction paths from  $E_{2007}$  to  $E^*$  over 35yrs

(a) Piecewise linear 
$$E_t = \begin{cases} E^* + (t-1)(E^* - E_{2007}) / (t^* - 1) & t < t^* \\ E^* & t \geq t^* \end{cases} \quad (6)$$

(b) Non-linear 
$$E_t = E^* + (E_{2007} - E^*) \left( \frac{1}{1+\theta} \right)^{t-1} \quad (7)$$

Find the values that would

- i) Maximize NPV over 35 yrs  
 $t^* = 35\text{yr}, \theta = 0.07$
- ii)  $\text{NPV}_{\text{Reduced effort}} = \text{NPV}_{\text{CCAMLR}}$   
 $t^* = 5.6\text{yr}, \theta = 0.5$



# Performance testing simulation

- Simulate the whole process of fishery management, including uncertainty

*E.g. Current MS*

- Process of stock assessment (with error  $CV=0.1$ )
  - Setting management actions (TAC level)
  - Implementation of the management actions (with error  $CV=0.017$ )
  - Impacts of the actions on the status of the stock and economic indicators
- Test the performance of candidate MSs using MSE

# Performance criteria

## *Stock conservation*

1. Probability that  $B_{2042} > 0.5K$
2. Probability of  $B_t < 0.2K$  during 35 yr

## *Economics*

3. NPV over 35 yr ( $\delta=0.02$ )
4. Median final year catch-per-unit-effort:  
 $CPUE_{2042}$

# Performance statistics

MS	Effort reduction	$p(B_{2042} > 0.5K)$	$p(B_t < 0.2K)$ in 35yr	NPV in 35yr	CPUE <sub>2042</sub>
CCAMLR		50.0%	0%	245.9	0.22
Effort-control	Immediate	99.7%	0%	229.2	0.26
	Linear				
	$t^* = 35$ yr	96.5%	0%	282.3	0.25
	$t^* = 5.6$ yr	99.7%	0%	245.9	0.26
	Non-linear				
	$v = 0.075$	98.0%	0%	272.4	0.24
	$v = 0.538$	99.7%	0%	245.9	0.25



Gradual effort reduction MSs outperformed the precautionary TAC-based MS in all criteria

# Discussion

- Economic-oriented strategy has potential for meeting conservation objectives, improving economic performance
- Time-frame important consideration for the operationalization of bioeconomic reference points.
- Can be applied to evaluate a wide range of management scenarios, e.g. optimal enforcement to control IUU (Edward et al., 2010).
- Can be extended to suit to the Patagonian toothfish fisheries in Australian sub-Antarctic waters, although there are some challenges.

Edward, C.T.T., R. Hillary, E. Hoshino, J. Pearce and D. Agnew. 2010. Bioeconomic evaluation of fisheries enforcement effort using a multifleet simulation model. *Fisheries Research* 107:253-260

# AUS Patagonian toothfish fisheries

- Multi-gear (trawl, longline, pots)
  - Requires an age-structured model
- Meta-population
- Multi-national (France)

