The Fishery on Antarctic Krill: Defining an Ecosystem Approach to Management

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Roger P. Hewitt
Southwest Fisheries Science Center
La Jolla, California

What's an ecosystem-based approach to management?

- Incorporation of environmental variability in models that predict population response to harvest
- Consideration of food web structure
- Incorporation of spatial variability of life history traits, predation pressure, movement patterns
- Consideration of all human activities (fishing, aquaculture, mineral extraction, transportation, recreation, …)

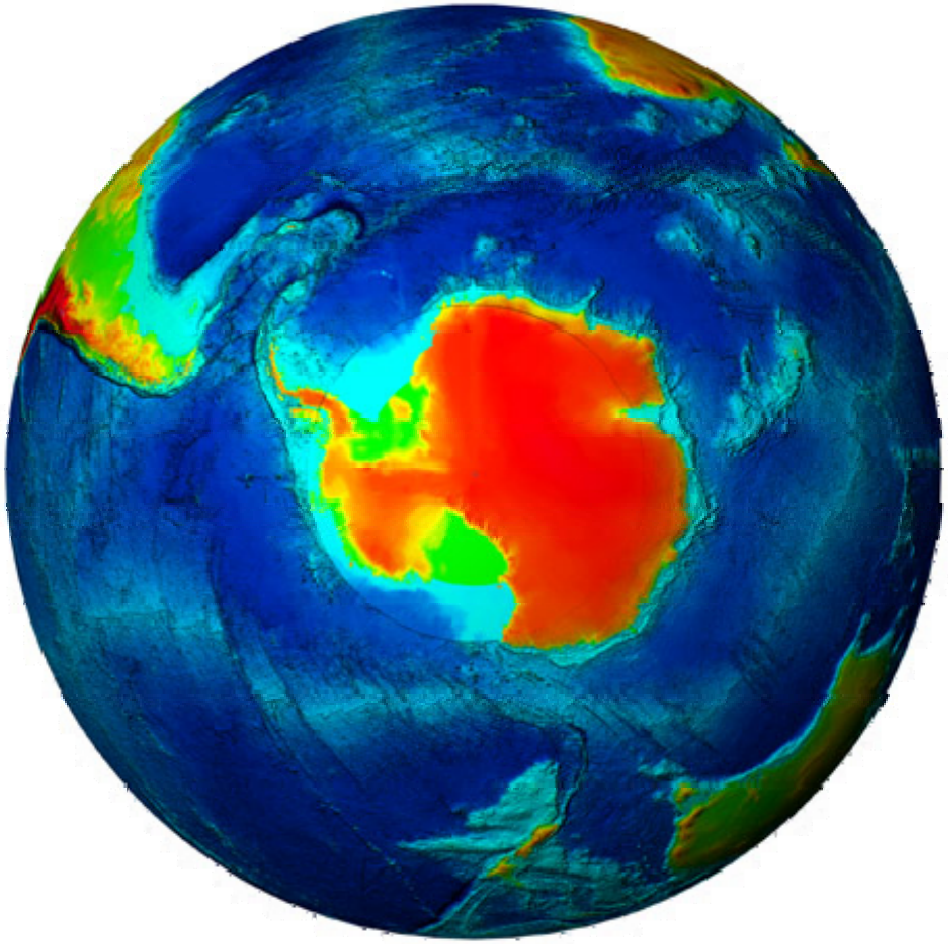
Antarctic krill fishery

- Targeted on a prey species
- Controlled by an international agreement
- Agreement is committed to preserving the stability and diversity of the pelagic ecosystem
- Kinds of information required to manage the fishery and the decision rules for its use are evolving as we learn more about the system

Outline

- Political institutions and mandates
- Natural economy of the krill-centric ecosystem including the krill fishery
- Precautionary catch limit
- Examples of patterns, trends and cycles from monitoring aspects of the krill-centric ecosystem
- Developing a management procedure for krill based on feedback from monitoring
- Comments on ecosystem monitoring and management

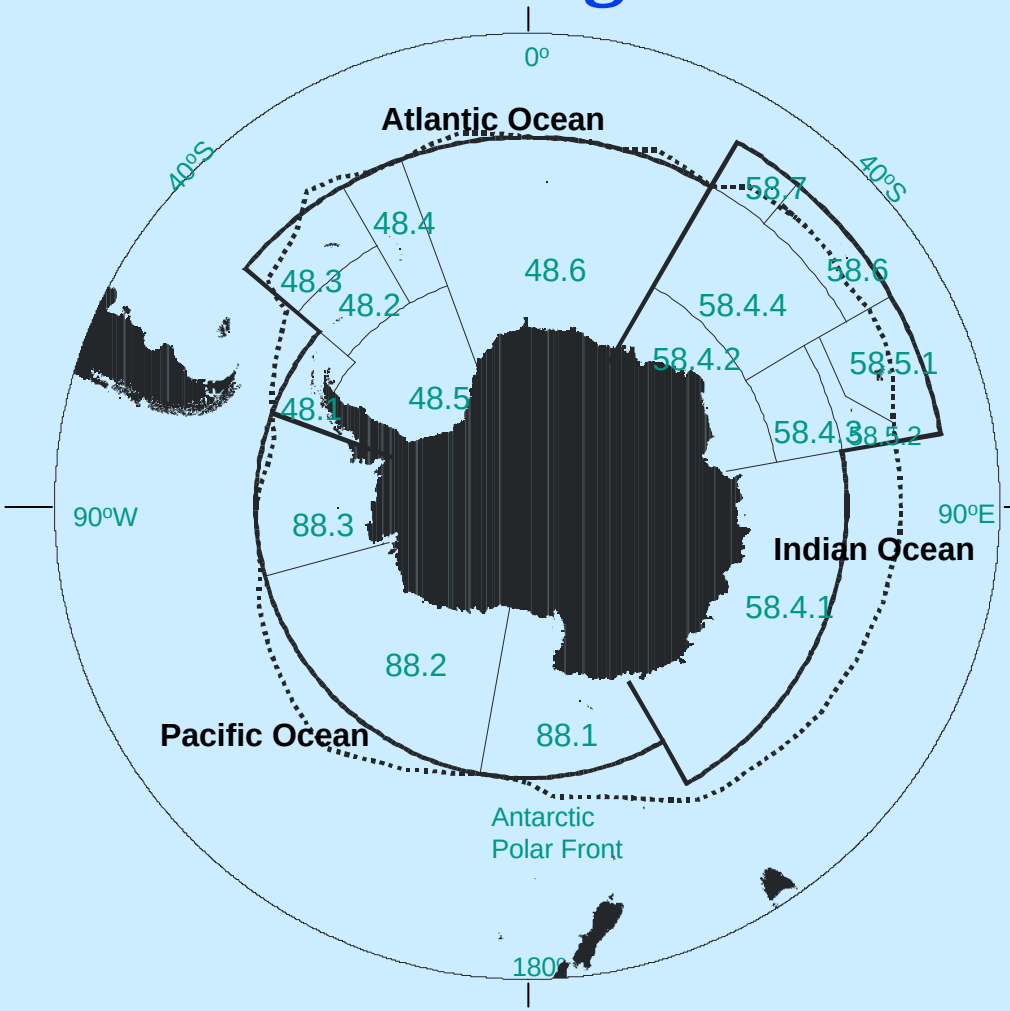
Antarctic Treaty (1961)



- Peaceful use, no military installations or testing of nuclear weapons
- Open access between Parties
- Neither recognizes nor abolishes territorial claims
- 12 original Parties, now 45

- Agreed Measures for the Conservation of Antarctic Flora and Fauna (1964)
- Convention for the Conservation of Antarctic Seals (1972)
- Convention for the Conservation of Antarctic Marine Living Resources (1980)
- Madrid Protocols (1991)

Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)



- Negotiated in late 1970s by Antarctic Treaty Consultative Parties
- Counter to FAO initiative
- Harmonized territorial claims with international resource management
- Convention boundaries approximate Antarctic Polar Front
- Competence for all living marine resources except seals and whales
- Consensus decision-making procedure
- 25 Signatory Members plus 9 acceding nations
- Permanent Secretariat in Hobart
- Commission, Scientific Committee and Working Groups

Intent of the Convention

- Conservation agreement – component of the Antarctic Treaty System

or

- Resource allocation agreement – i.e. a Regional Fishery Management Organization

Article II

1. Objective is conservation
2. Conservation includes rational use
3. Rational use (harvesting) conducted so as to:
   a. Prevent decrease in size of harvested populations below that necessary for stable recruitment
   b. Maintain ecological relationships between harvested, dependent and related species
   c. Prevent or minimize risk of changes not reversible over two or three decades

And further states:

> "… taking into account the state of available knowledge of ***the direct and indirect impacts of harvesting***, the effects of introduction of alien species, the effects of associated activities on the marine ecosystem, ***and the effects of environmental change***, with the aim of making possible the sustained conservation of Antarctic marine living resources."

Significance of Article II

- Resource management should follow:
  - **Precautionary approach** – in accordance with the mandate to minimize risk of change to ecosystem
  - **Ecosystem approach** – in accordance with the mandate to consider both trophic interactions and physical forcing

- Not defined:
  - Risk criteria and acceptable levels of risk
  - Acceptable and unacceptable levels of ecosystem change
  - Action required when causes of ecosystem change cannot be unambiguously attributed to either the fishery or the environment

A very brief history of CCAMLR

First 10 years

- Conservation oriented Members outnumbered fishing Members, but adoption of conservation measures required consensus
- Krill harvest small compared to estimates of predator consumption
- Little scientific information on which to assess the status of krill stocks and related ecosystem components
- Resistance to fishery restrictions, few conservation measures adopted
- Focused on severely depleted finfish stocks
- Established CCAMLR Ecosystem Monitoring Program (CEMP)

Since early 1990s

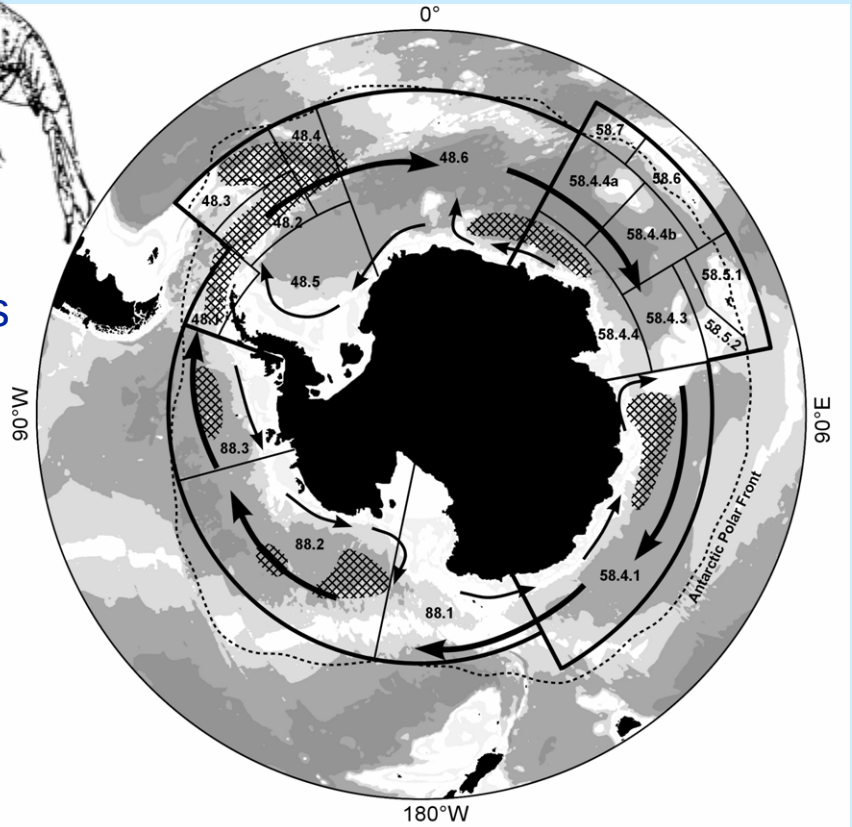
- Precautionary catch limit for krill
- Management procedures for 7 assessed and 3 exploratory fisheries
- Catch Documentation Scheme for toothfish (Chilean seabass)
- Mitigation measures for reducing seabird by-catch

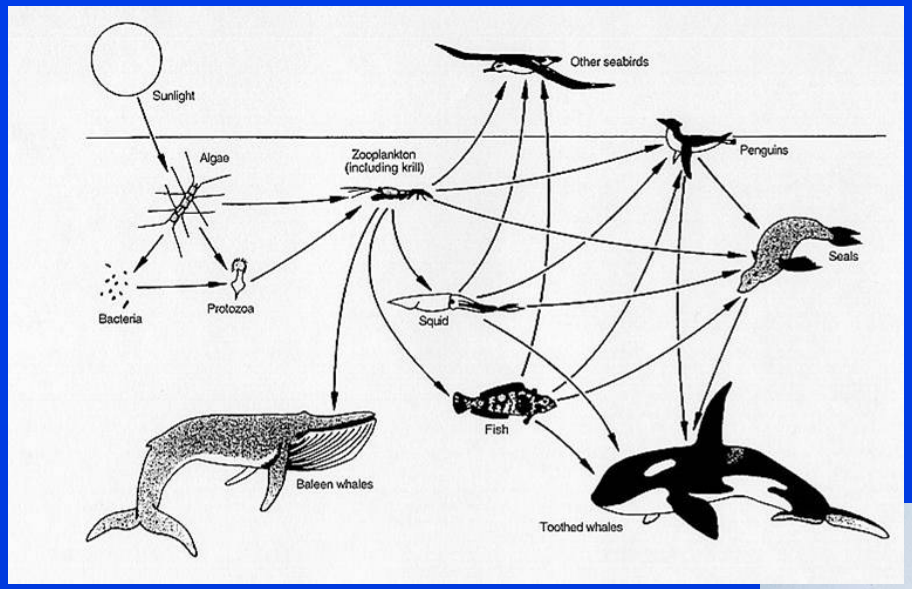
Factors

- Large scale krill harvesting did not develop as first expected - fluoride in krill, rapid autolysis, processing technology, market development
- Other fisheries developed, more Members with interests in both conservation and harvest
- Political and economic instability in Russia and the Ukraine as USSR dissolved

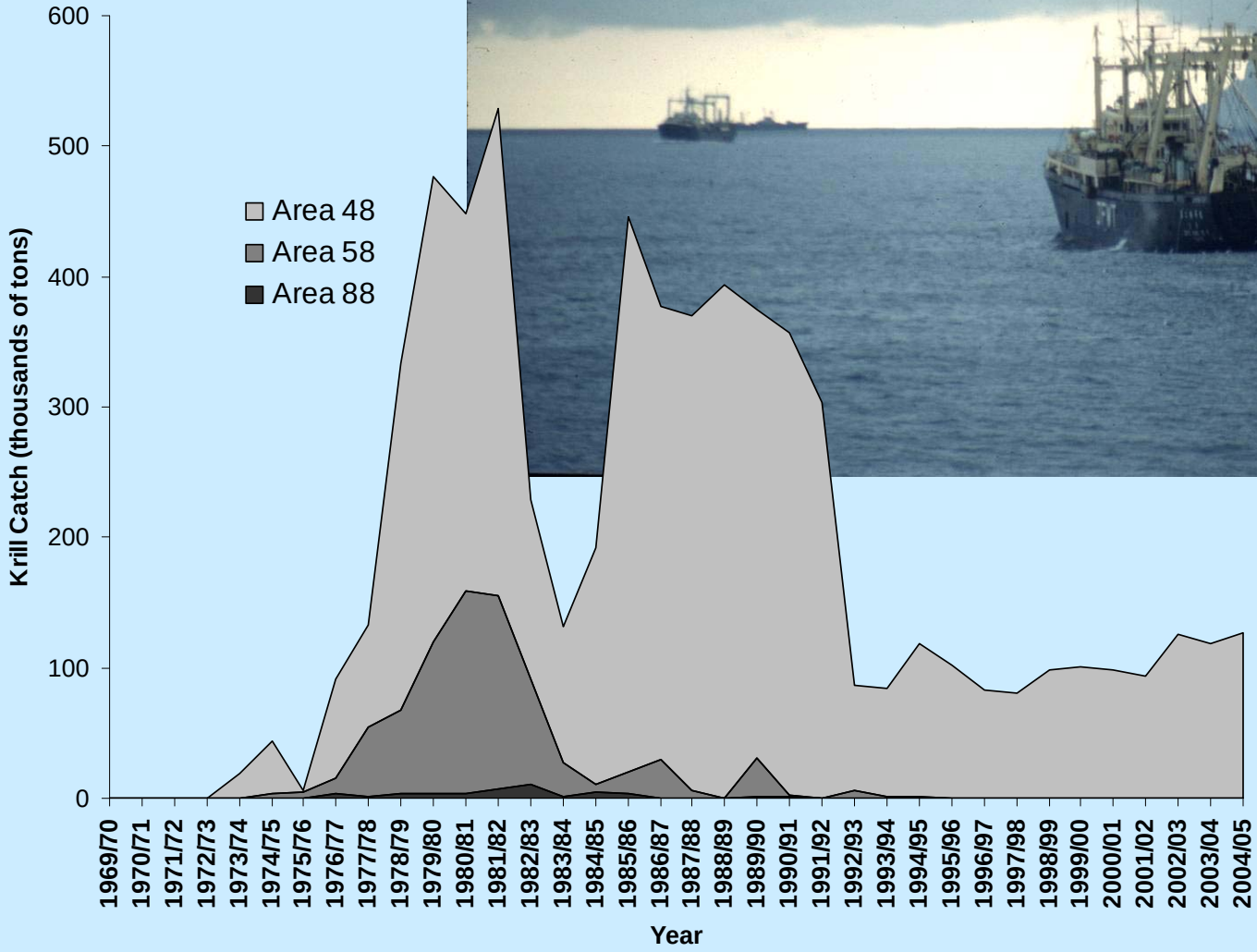
Antarctic Krill, *Euphausia superba* Dana

- Largest, longest lived and greatest biomass of major euphausiid species
- Associated with permanent large-scale anti-cyclonic gyres
- Largest concentration in southwest Atlantic sector together with large numbers of krill consuming birds, whales and seals
- 5-7 year longevity in the wild
- Hierarchical organization – swarms and clusters of swarms
- Key species in natural economy





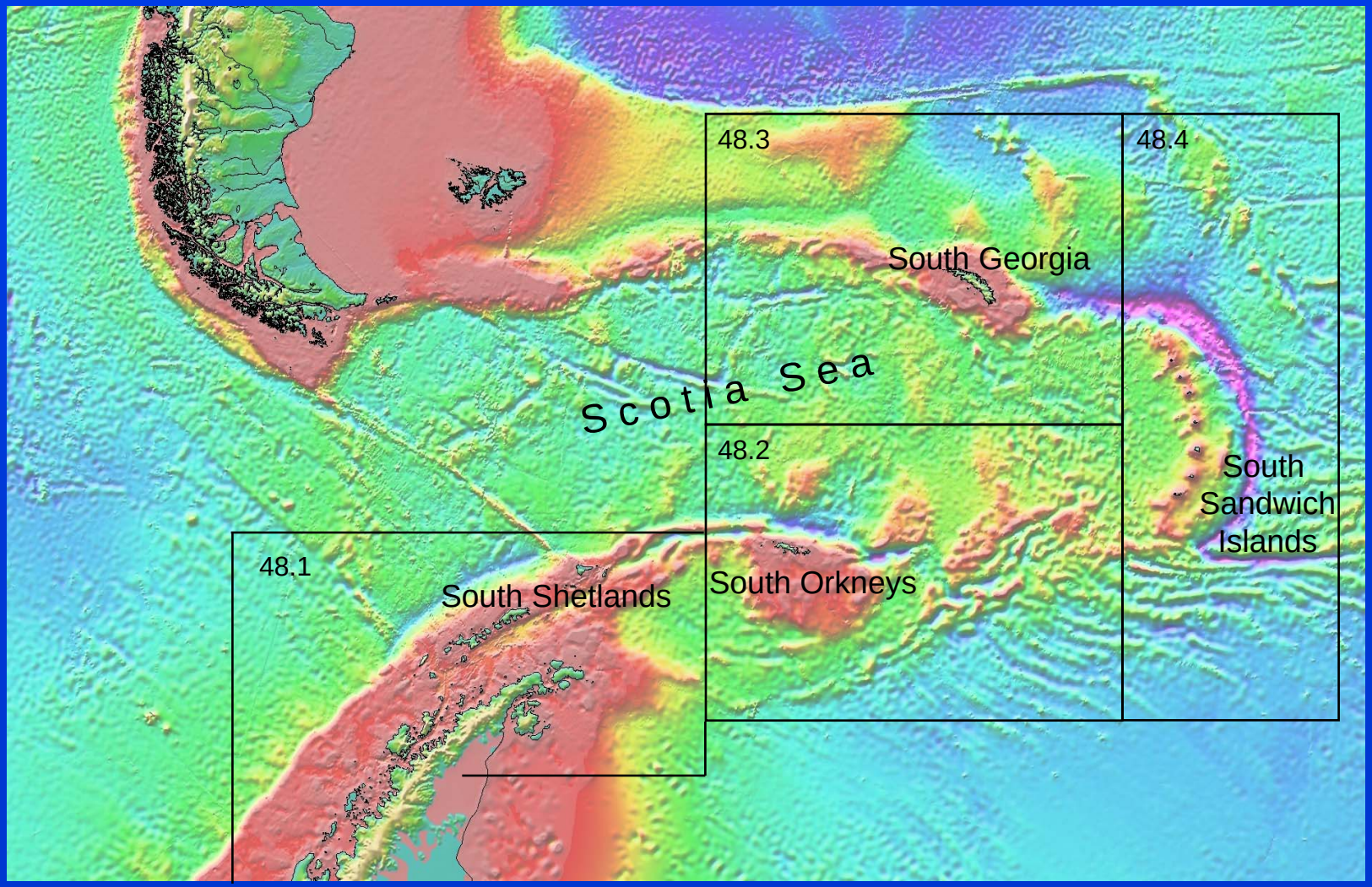
Baleen whales	30 - 45 million tons
Seals	120 -150
Penguins and other birds	20 - 30
Squid	30 - 50
Fish	10 - 20
Total annual demand	**250 ± 50 million tons**


Area 48
Area 58
Area 88
Krill Catch (thousands of tons)
600
500
400
300
200
100
0
1969/70
1970/71
1971/72
1972/73
1973/74
1974/75
1975/76
1976/77
1977/78
1978/79
1979/80
1980/81
1981/82
1982/83
1983/84
1984/85
1985/86
1986/87
1987/88
1988/89
1989/90
1990/91
1991/92
1992/93
1993/94
1994/95
1995/96
1996/97
1997/98
1998/99
1999/00
2000/01
2001/02
2002/03
2003/04
2004/05
Year

Krill fishing Members and their products

- Argentina, Chile, Germany, Japan, Korea, Latvia, Norway, Panama, Poland, Russia, Spain, Ukraine, United Kingdom, USA, Vanuatu
- Current krill fishing Members
  - Japan 18%
  - Korea 21%
  - Poland 3%
  - Ukraine 18%
  - USA 2%
  - Norway 38%
- Human consumption, protein concentrates, pharmaceutical derivatives, chitin products, meal, aquaculture feed
- 100% of current catch from Area 48

Area 48 (Scotia Sea)



Yield model

- Information lacking on:
  - Demand by krill predators
  - Dispersion and movement of krill throughout their habitat
  - Variability in recruitment and the factors that influence it

- Yield is a proportion of the unexploited population biomass

$$Y = \gamma B_0$$

- Age-structured population simulation model
- PDFs of initial abundance, growth, mortality, maturity and recruitment

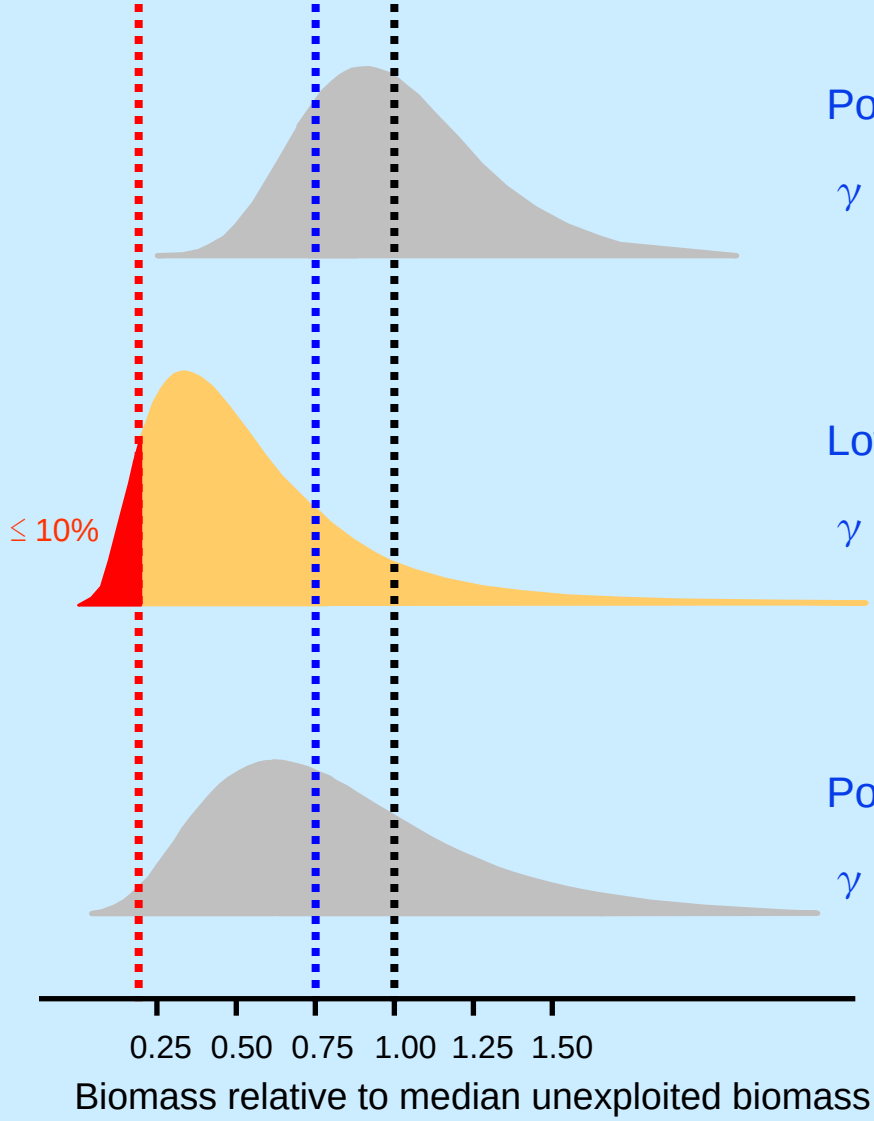
  Incorporate both natural variability and measurement uncertainty
- Management objectives and decision rules

Gulland 1971
Beddington and Cooke 1983
Butterworth et al 1992, 1994
Constable and de la Mare 1996
Constable et al. 2000

Operational definitions of Article II

- Prevent decrease in size of harvested populations below that necessary for stable recruitment
  - Probability that spawning biomass in any one year falls below 20% of unexploited median biomass should be 10% or less
- Maintain ecological relationships between harvested, dependent and related species
  - Median level of spawning biomass should be 75% or greater of unexploited median biomass
- Prevent or minimize risk of changes not reversible over two or three decades
  - Run simulations for a minimum of 20 years

Two-part decision rule



Population biomass

$\gamma = 0$

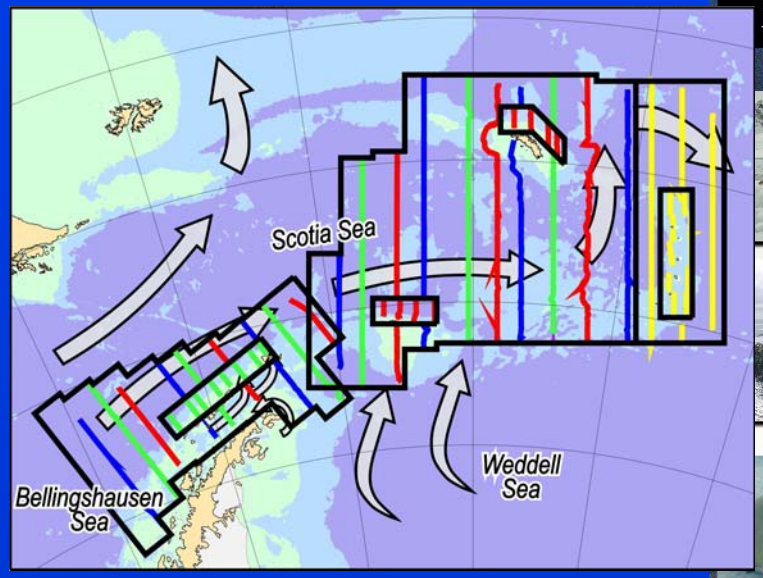
Lowest population biomass

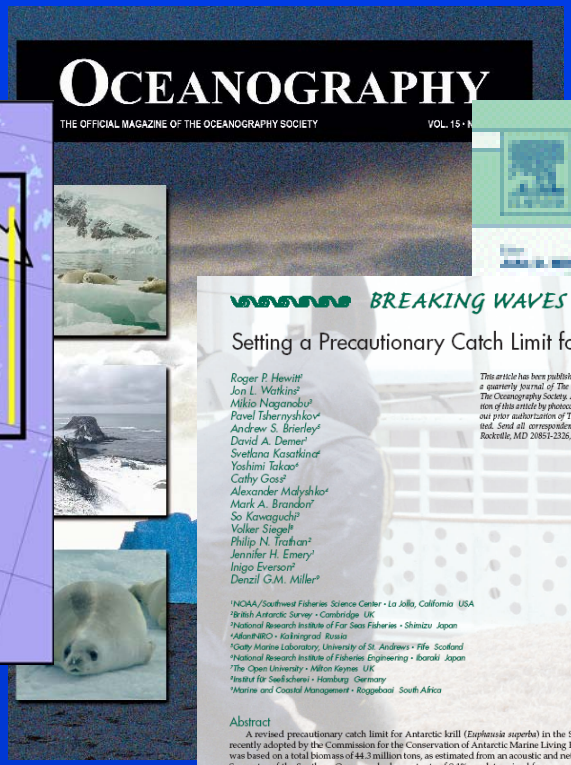
$\gamma > 0$

Population biomass

$\gamma > 0$

CCAMLR 2000 Survey





BREAKING WAVES

Setting a Precautionary Catch Limit for Antarctic Krill

Roger P. Hewitt[1]
Jon L. Watkins[2]
Mikio Naganobu[3]
Pavel Tshernyshkov[4]
Andrew S. Brierley[5]
David A. Demer[1]
Svetlana Kasatkina[6]
Yoshimi Takao[3]
Cathy Goss[2]
Alexander Malyshko[4]
Mark A. Brandon[7]
So Kawaguchi[3]
Volker Siegel[8]
Philip N. Trathan[2]
Jenniter H. Emery[1]
Inigo Everson[2]
Denzil G.M. Miller[9]

[1]NOAA/Southwest Fisheries Science Center • La Jolla, California USA
[2]British Antarctic Survey • Cambridge UK
[3]National Research Institute of Far Seas Fisheries • Shimizu Japan
[4]AtlantNIRO • Kaliningrad Russia
[5]Gatty Marine Laboratory, University of St. Andrews • Fife Scotland
[6]National Research Institute of Fisheries Engineering • Ibaraki Japan
[7]The Open University • Milton Keynes UK
[8]Institut für Seefischerei • Hamburg Germany
[9]Marine and Coastal Management • Roggebaai South Africa

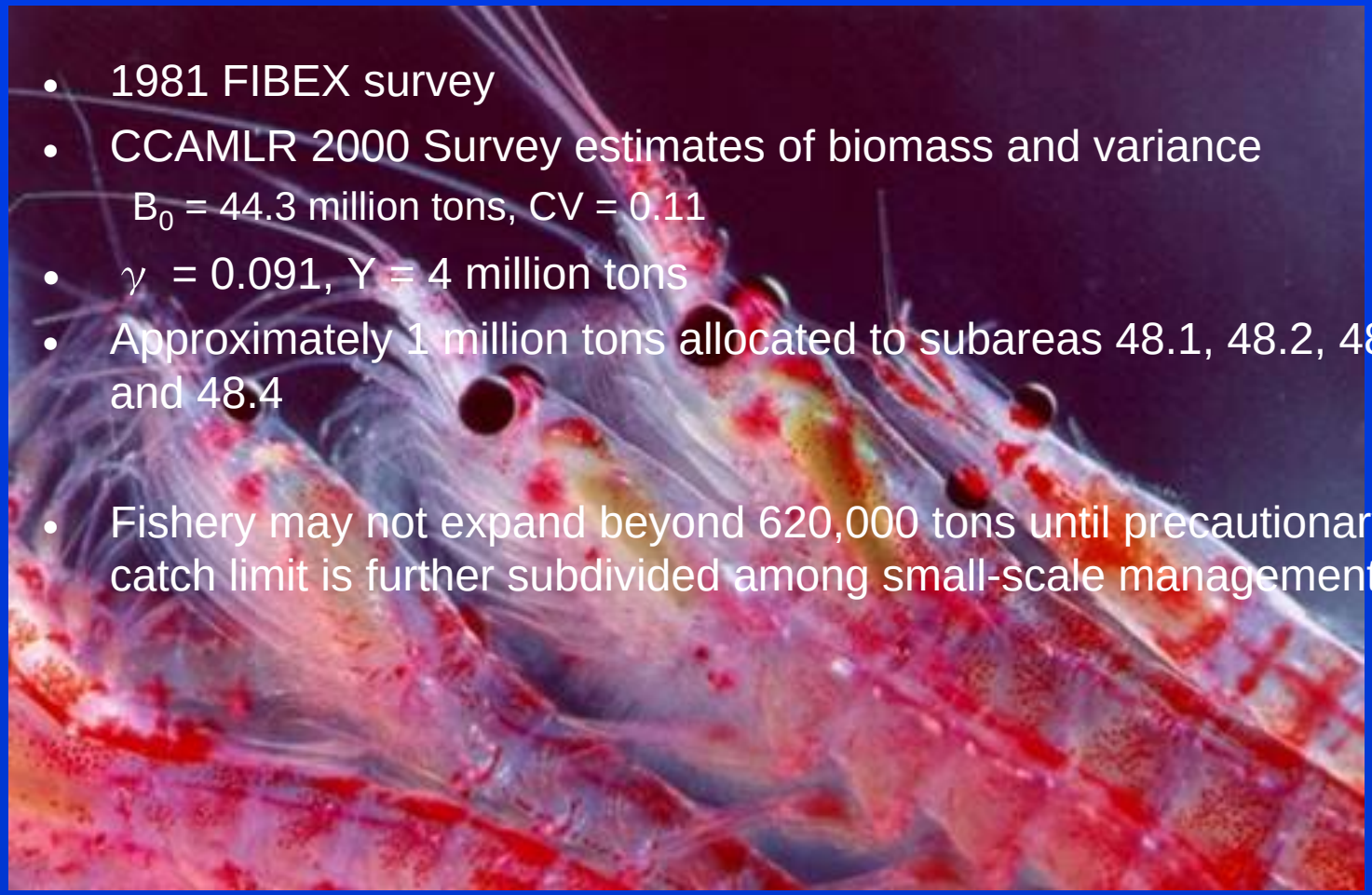
Abstract

A revised precautionary catch limit for Antarctic krill (*Euphausia superba*) in the Scotia Sea of 4 million tons was recently adopted by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). The limit was based on a total biomass of 44.3 million tons, as estimated from an acoustic and net survey of krill across the Scotia Sea sector of the Southern Ocean, and a harvest rate of 9.1%, as determined from an analysis of the risks of exceeding defined conservation criteria. We caution, however, that before the fishery can expand to the 4-million-ton level it will be necessary to establish mechanisms to avoid concentration of fishing effort, particularly in proximity to colonies of land-breeding krill predators, and to consider the effects of krill immigrating into the region from multiple sources.

The Antarctic Circumpolar Current (ACC) concentrates and accelerates as it passes through Drake Passage transporting massive quantities of water from the Bellingshausen Sea (southeast Pacific) to the Scotia Sea (southwest Atlantic) sectors of the Southern Ocean. High concentrations of Antarctic krill (*Euphausia superba*) and krill predators are located in this region (Marr, 1963; Laws, 1985) as well as an international fishery targeting krill (Agnew and Nicol, 1996). The fishery is regulated under the Convention for the Conservation of Antarctic Marine Living Resources (CAMLR), part of the Antarctic Treaty system (Box 1). Article II of Convention mandates that fisheries be managed such that: a) the size of harvested populations is sufficient to ensure stable recruitment; b) ecological relationships between harvested and dependent populations are maintained; and c) changes to the marine ecosystem that cannot be reversed over two or three decades are prevented. In order to meet this charge CCAMLR adopted a precautionary approach whereby the provi-

Background image: Scientific catch of Antarctic krill aboard South African R/V *Africana*. Photo by R. Hewitt.

Operation of yield model



- 1981 FIBEX survey
- CCAMLR 2000 Survey estimates of biomass and variance
  B_0 = 44.3 million tons, CV = 0.11
- γ = 0.091, Y = 4 million tons
- Approximately 1 million tons allocated to subareas 48.1, 48.2, 48.3 and 48.4

- Fishery may not expand beyond 620,000 tons until precautionary catch limit is further subdivided among small-scale management units

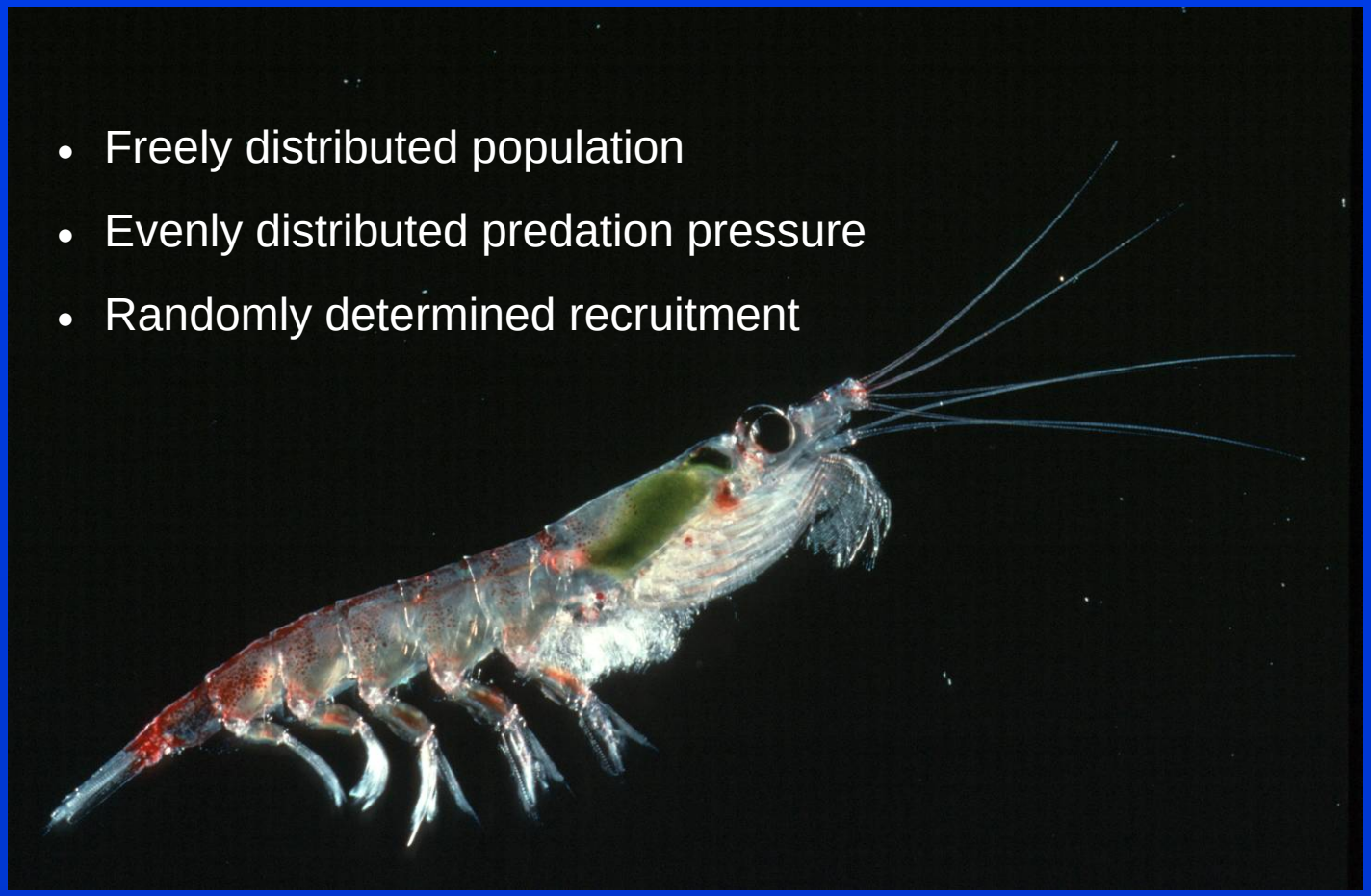
CCAMLR's management approach

- Develop operational definitions of the resource management guidelines contained in the Convention;
- Develop conservation criteria that quantify the definitions;
- Assess the risks of exceeding the criteria; and
- Adopt decision rules for controlling the fishery based on the assessment.

- High uncertainty leads to broad distributions and conservative management.
- Conversely, more data will contribute to higher precision and less restrictive management.

- **Setting management objectives and acceptable levels of risk accomplished in political forum.**
- **Assessments and application of decision rules accomplished in scientific forum.**

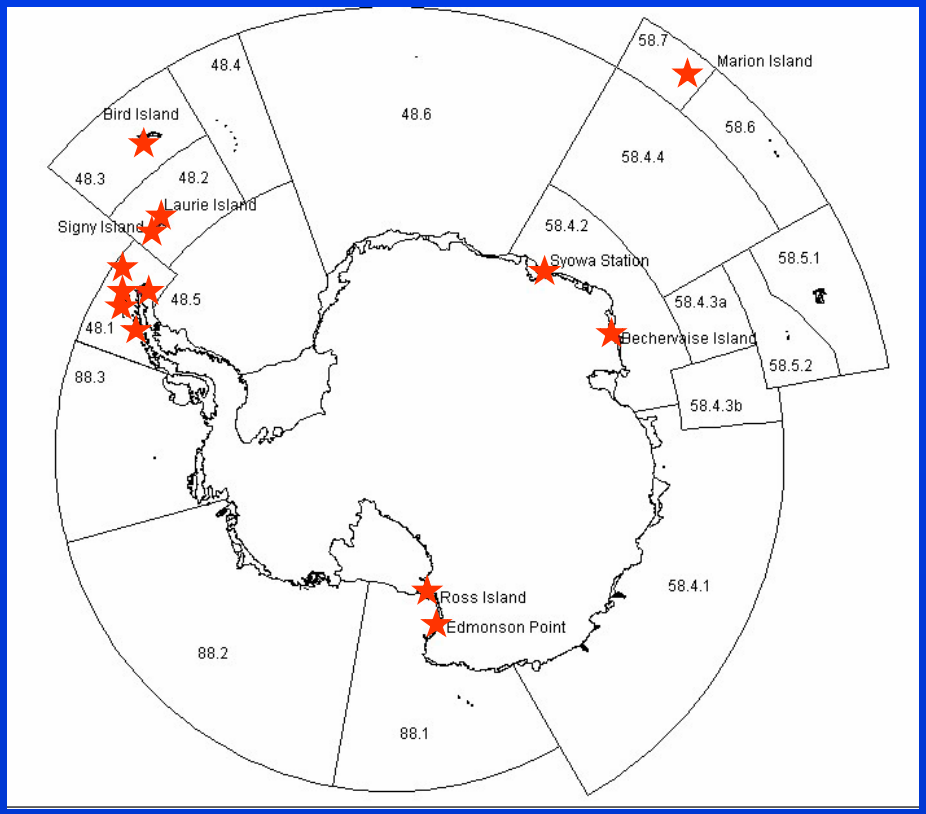
Yield model assumptions



CCAMLR Ecosystem Monitoring Program (CEMP)

- Objectives
  - Detect and record significant changes in critical components of the ecosystem to serve as a basis for the conservation of Antarctic marine living resources
  - Distinguish between changes due to the harvesting of commercial species and changes due to environmental variability, both physical and biological
- Criteria for indicator species
  - Feed predominately on krill, wide geographic range, represent important ecosystem components
  - Crabeater and Antarctic fur seals, Adelie, gentoo, chinstrap and macaroni penguins, Antarctic and Cape petrels, black-browed albatrosses
  - Indices of reproductive performance, growth and condition, feeding ecology, abundance
- Environmental indices (sea ice extent, meteorological conditions, hydrographic conditions)

CEMP sites



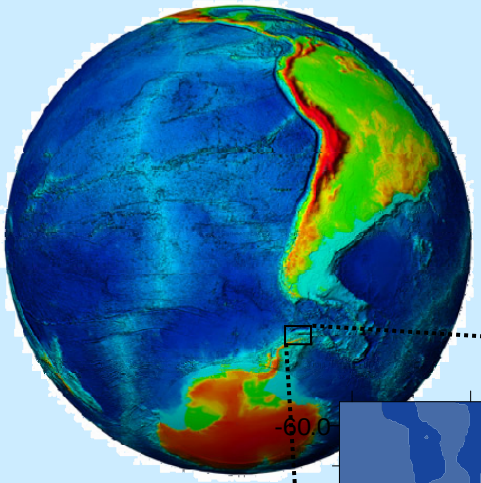
- Member participation is voluntary
- Standard protocols for data collection and derivation of indices
- Data and indices submitted to Secretariat
- Prey surveys at selected sites

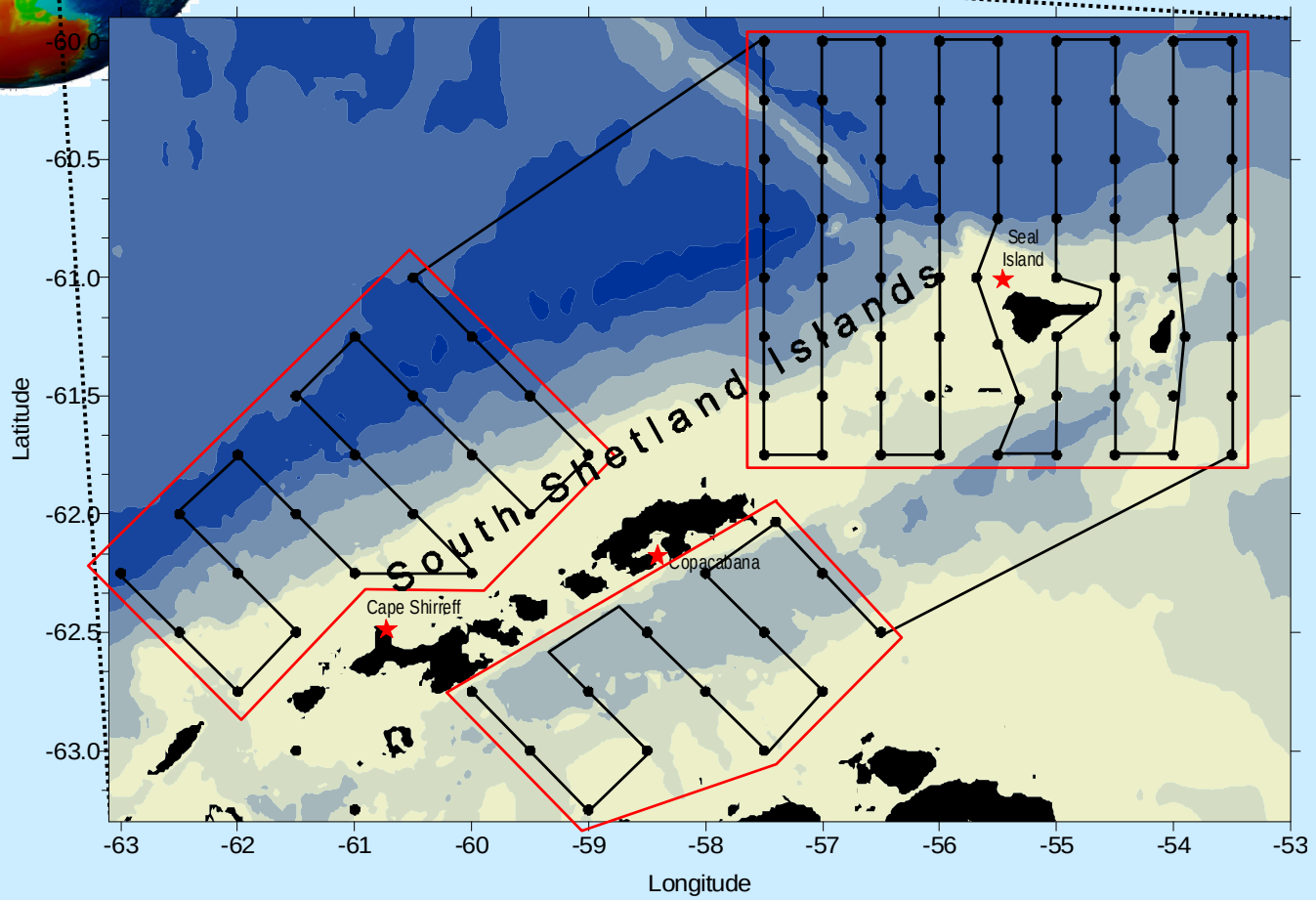
US AMLR Program

- Surveys of finfish, crabs and krill in support of CCAMLR
- Long-term monitoring program in South Shetland Islands
- Land-based monitoring of predator foraging ecology and reproductive performance
- Ship-based surveys of krill and oceanographic conditions
- Working hypotheses
  - Availability of krill is affected by both physical and biological aspects of their habitat
  - Land-breeding krill predators respond to variations in the availability of their prey

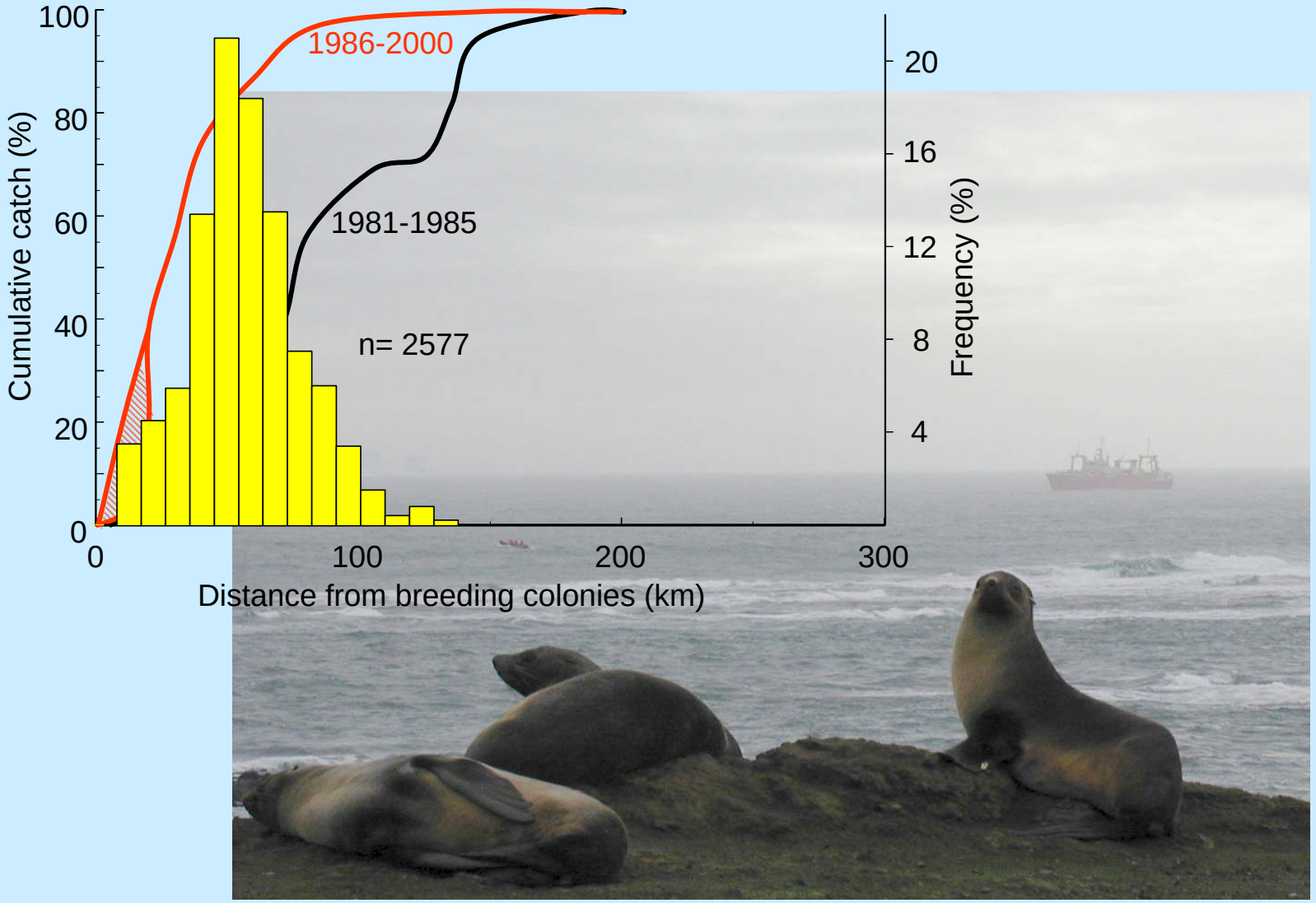
South Shetland Islands

- ~ 2 million tons of krill
- ~ 0.8 million tons consumed annually by fur seals and penguins
- ~ 1 million tons consumed annually by baleen whales and crabeater seals

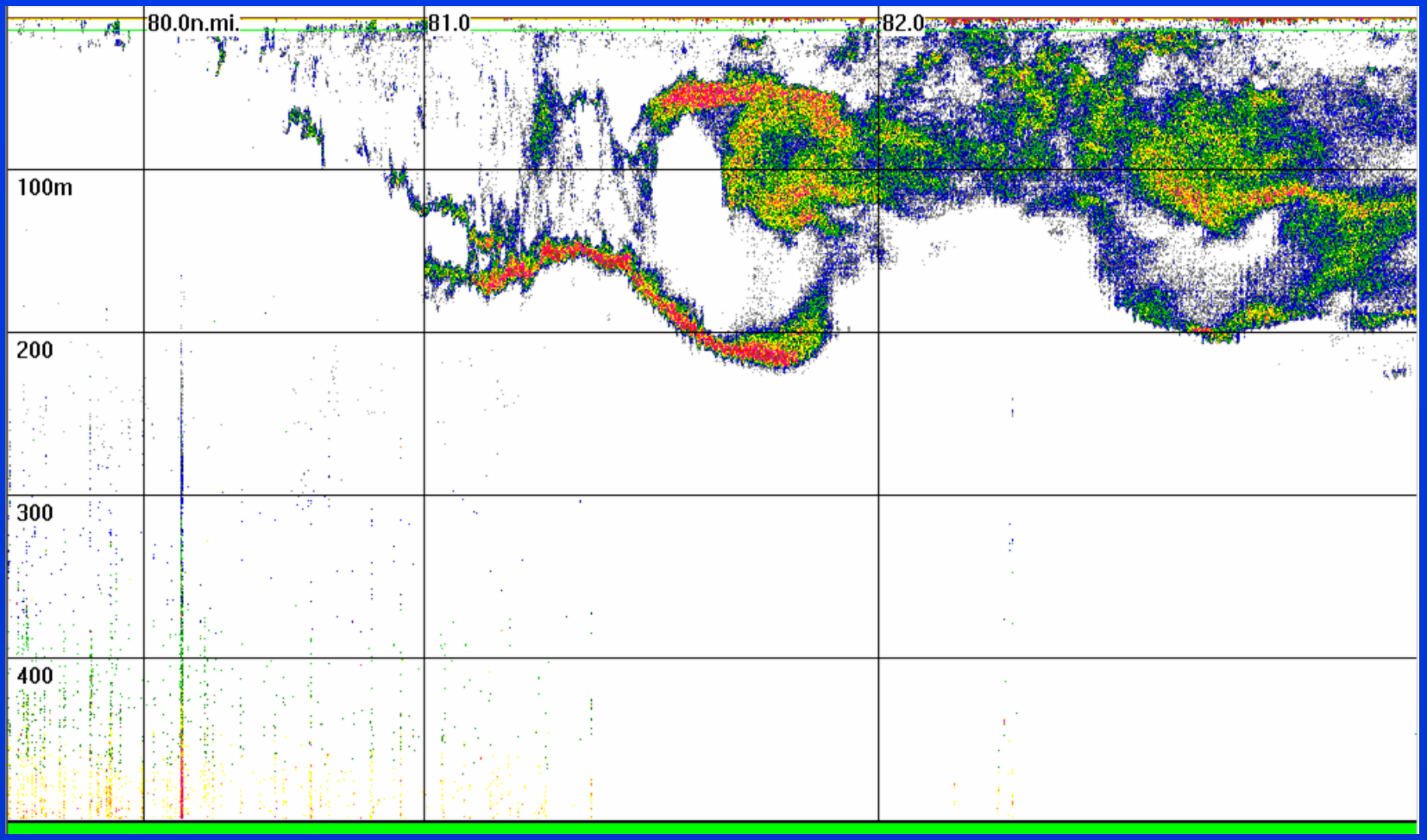


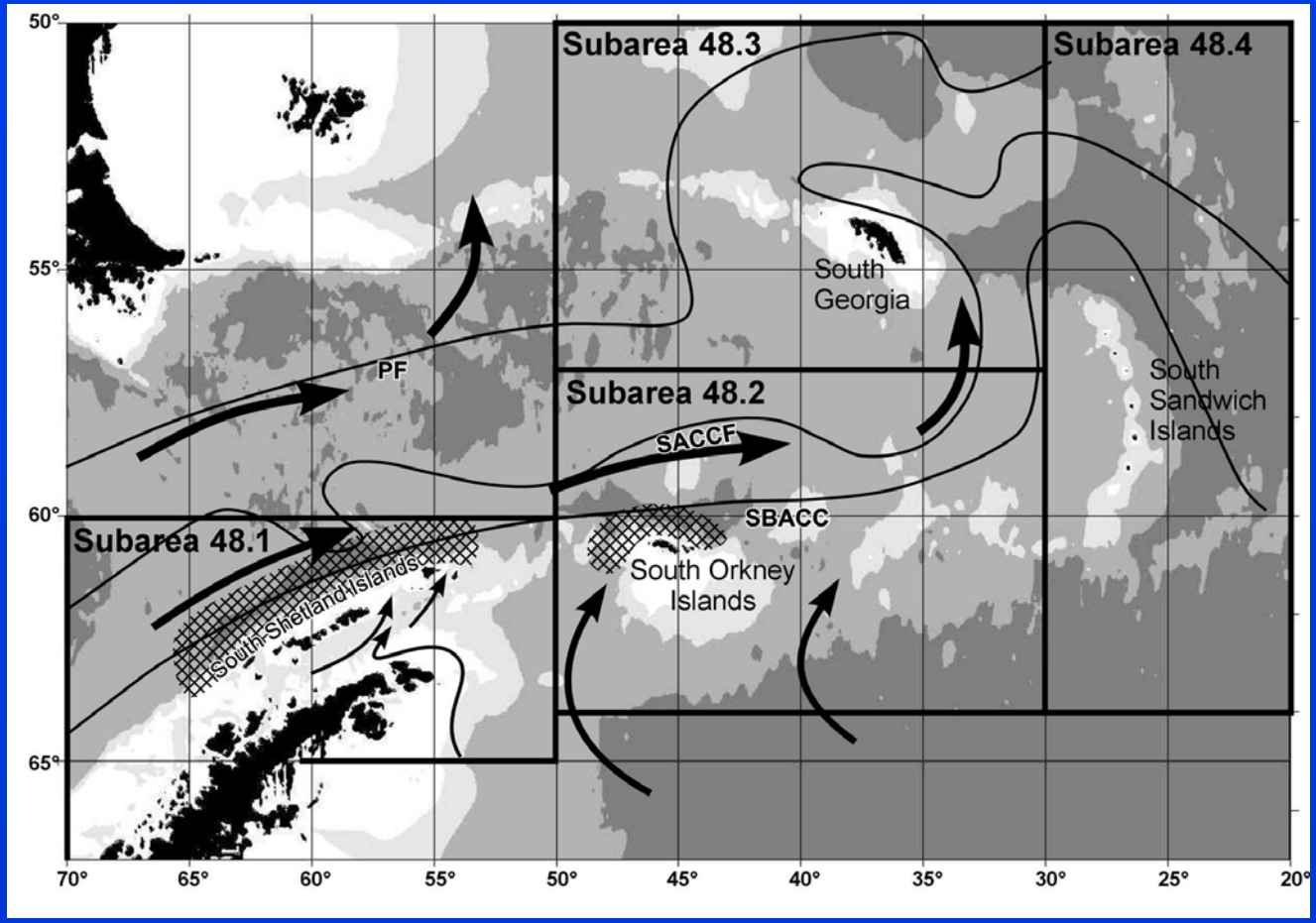


Proximity of fishing and foraging to breeding colonies



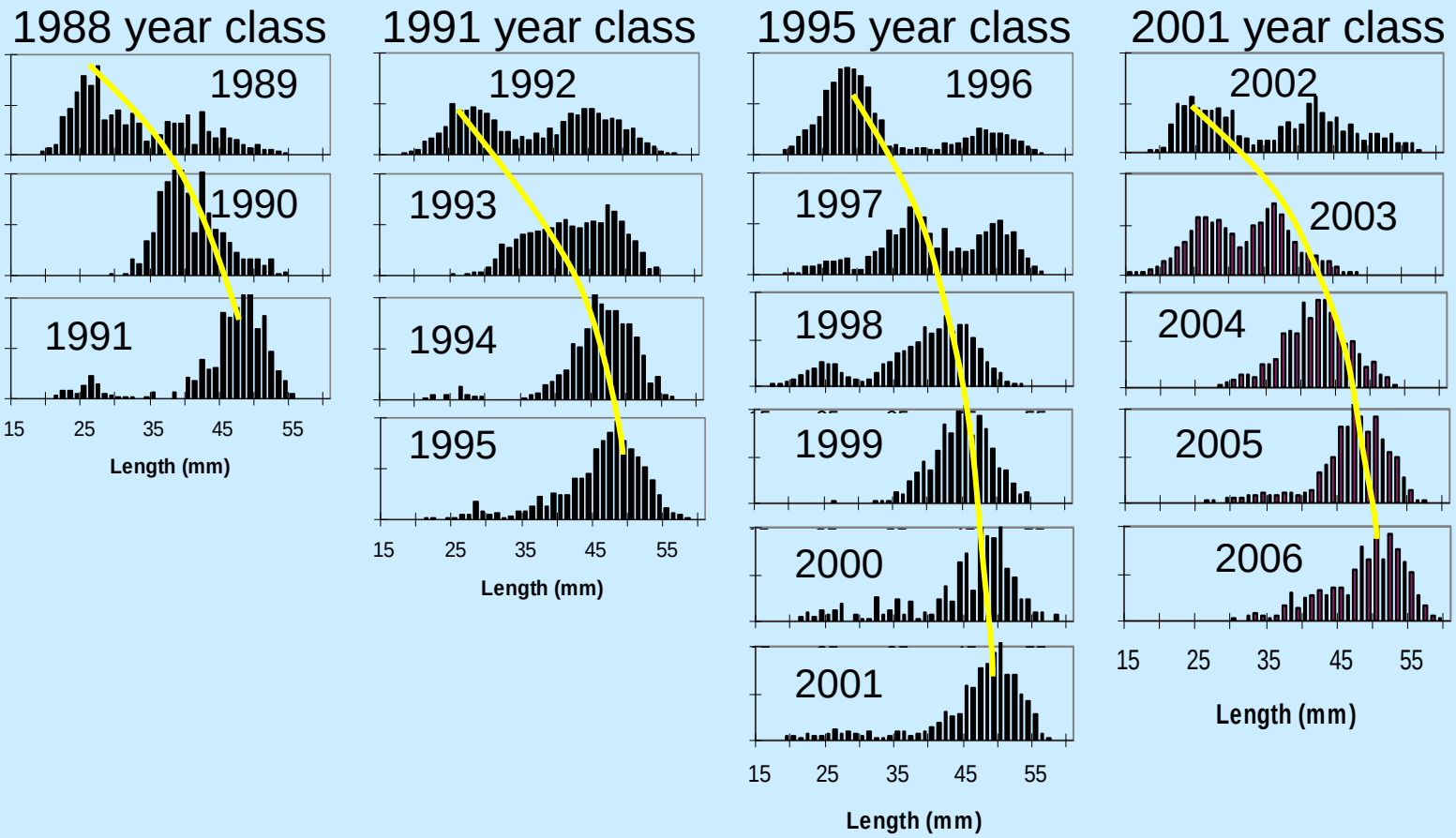
Gyres, eddies and sheer zones are distribution loci

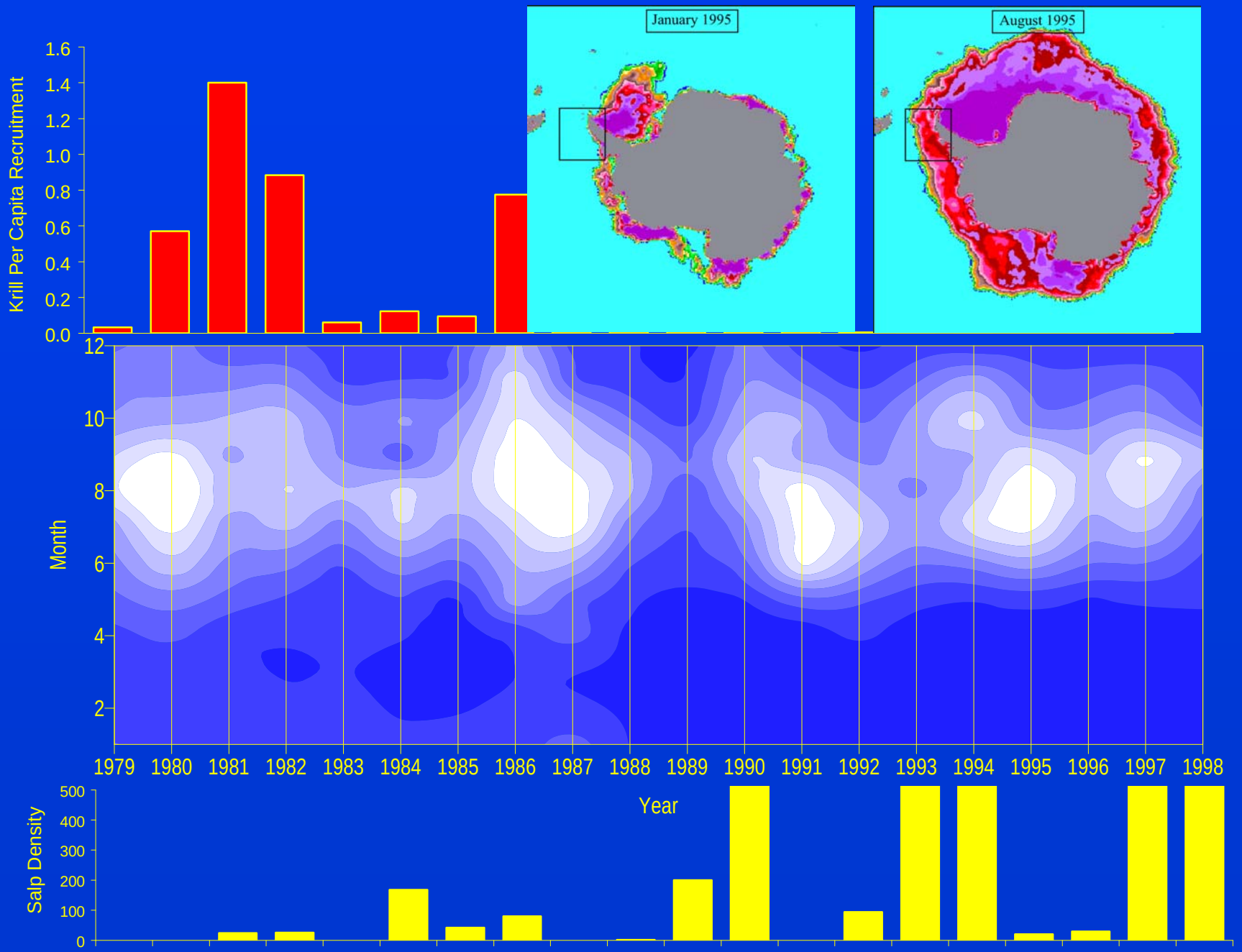




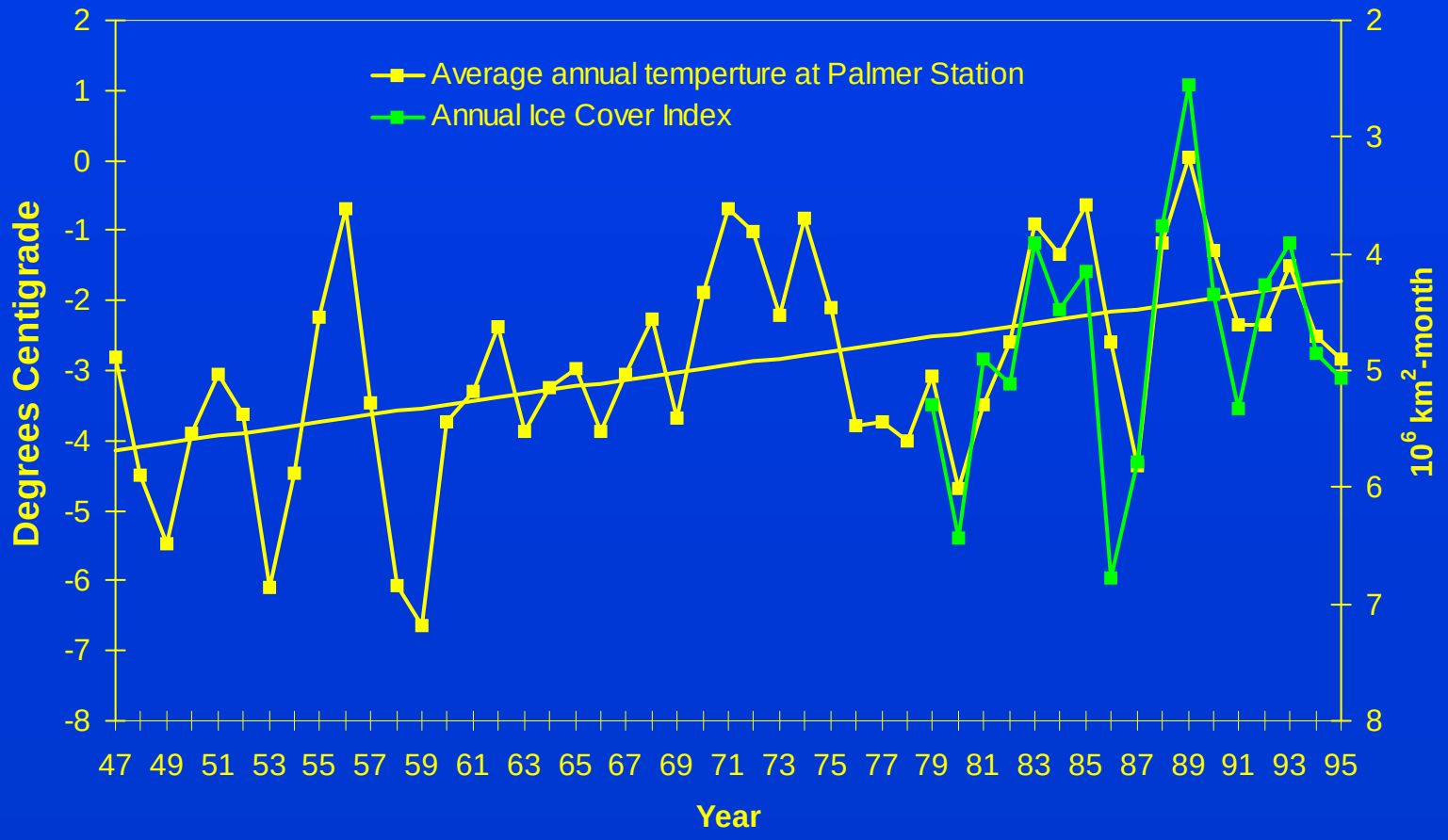
- West to east transport with ACC
- Aggregate along frontal zones and shelf breaks
- Sources in Bellingshausen and Scotia Sea
- Two spawning areas

Krill population is sustained by occasional strong year classes




Krill Per Capita Recruitment
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
January 1995
August 1995
Month
12
10
8
6
4
2
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year
Salp Density
500
400
300
200
100
0

Warming trend near Antarctic Peninsula



What controls krill recruitment

Strong year class results from:

- Good over-wintering conditions for adult krill
- Early and repeated spawning
- Slow salp population growth during spring
- Good survival of larvae through first winter

Associated with extensive winter sea ice development

Warming trend implies:

- Change in dominance between krill and salps
- Less energy transfer to vertebrate predators

V. Loeb, V. Siegel, O. Holm-Hansen, R. Hewitt, W. Fraser, W. and S. Trivelpiece.
Effects of sea-ice extent and krill or salp dominance on the Antarctic food web.
1997. *Nature* 387: 897-900.

Salp versus copepod years

Ecosystem variability 1993 – 2000

- Salp demographics
- zooplankton composition
- primary productivity
- Hydrography

- Salp years (1993 and 1998)
  - Low sea ice development
  - Low Chl-a concentrations
  - High salp production
  - Low copepod abundance
  - Low krill spawning and recruitment success
- Copepod years (1995, 1996, 2000)
  - Extensive sea ice development
  - High Chl-a concentrations
  - Low salp production
  - High copepod abundance
  - Good krill spawning and reproductive success
- Transition years (1994, 1999)
  - Rapid, within season shifts
  - Implies physical rather than biological causes

Krill management issues and initiatives

- Concentration of krill catches near breeding colonies
- Feedback from localized monitoring to region-wide population yield model

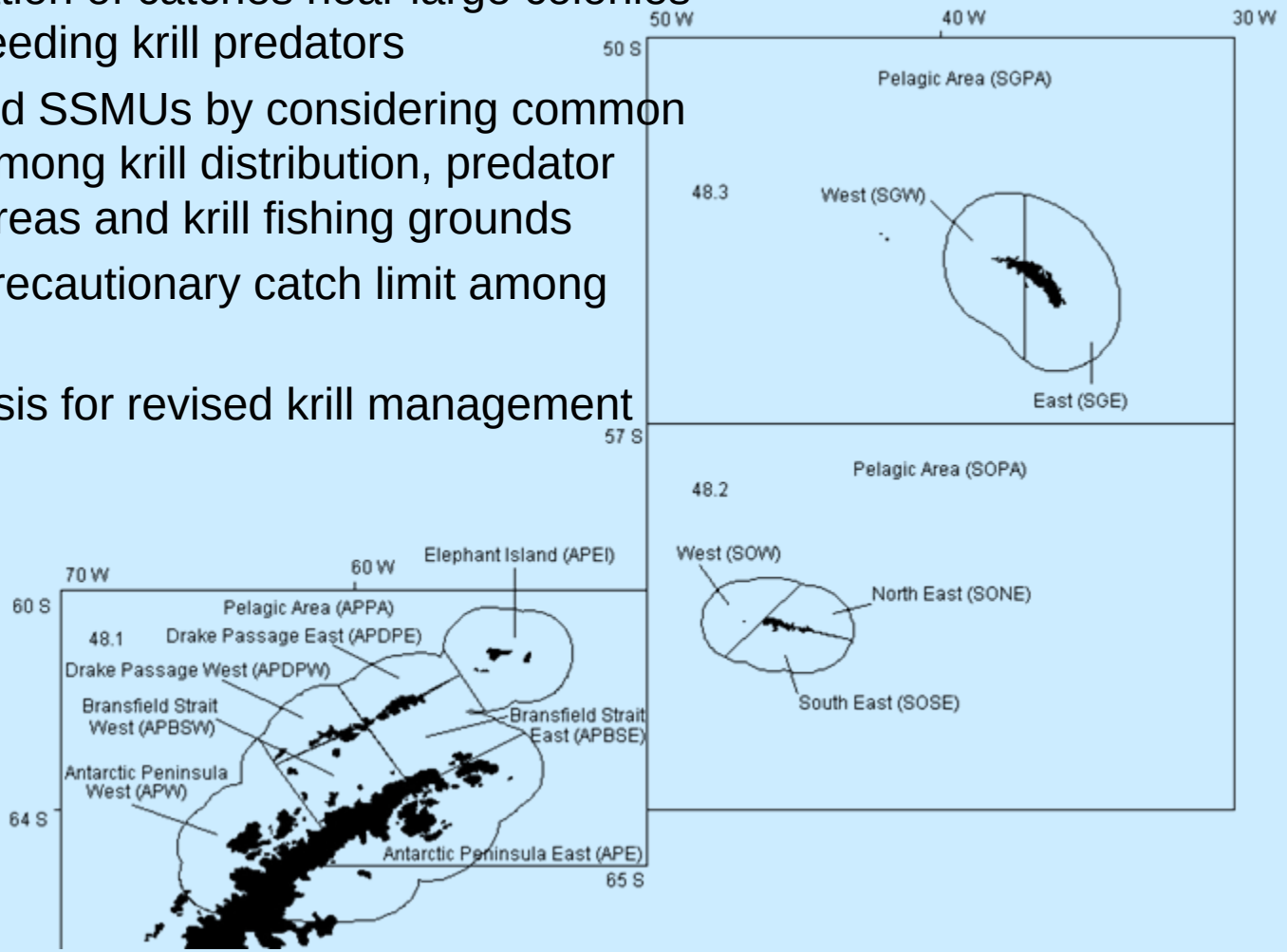
- CEMP Working Group (1986-95)
  - Standardized monitoring protocols and indices
- Krill Working Group (1989-95)
  - Precautionary catch limit for krill
- WG on Ecosystem Monitoring and Management (1996-presnt)
  - Revised krill management procedure
  - Small-scale management units

Revised Krill Management Procedure

	Year 1	Year 2	Year 3	Year 4
Delineation of small-scale management units in Area 48	Workshop			
CEMP review	Planning session	Workshop	Consideration of further analytical work	
Selection of appropriate operational models incorporating predator–prey–environment–fishery interactions	Discussion	Planning session	Workshop	
Evaluation of management procedures including management objectives, required observations, assessment methods, and decision rules	Discussion	Discussion	Planning session	Workshop
Reporting requirements from fishery	Discussion	Interim requirements adopted by Commission	Consideration of revised requirements	Recommendation
Monitoring requirements from CEMP	Discussion	Discussion	Initial specifications	Revised specifications

Small-Scale Management Units

- Concentration of catches near large colonies of land-breeding krill predators
- Established SSMUs by considering common patterns among krill distribution, predator foraging areas and krill fishing grounds
- Allocate precautionary catch limit among SSMUs
- Spatial basis for revised krill management procedure



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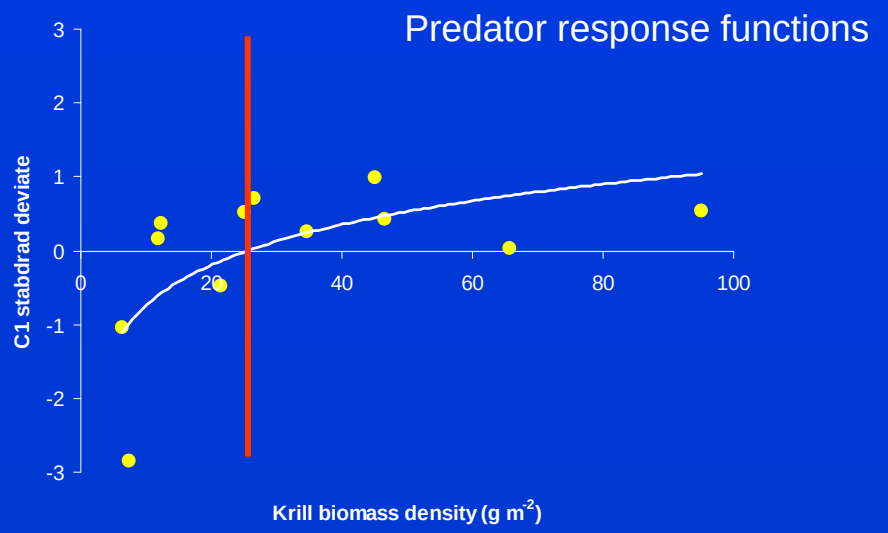
CEMP Review

- Power of indices or combination of indices to detect change
- Ability to attribute detectable change to fishery or environment
- Derive useful management advice



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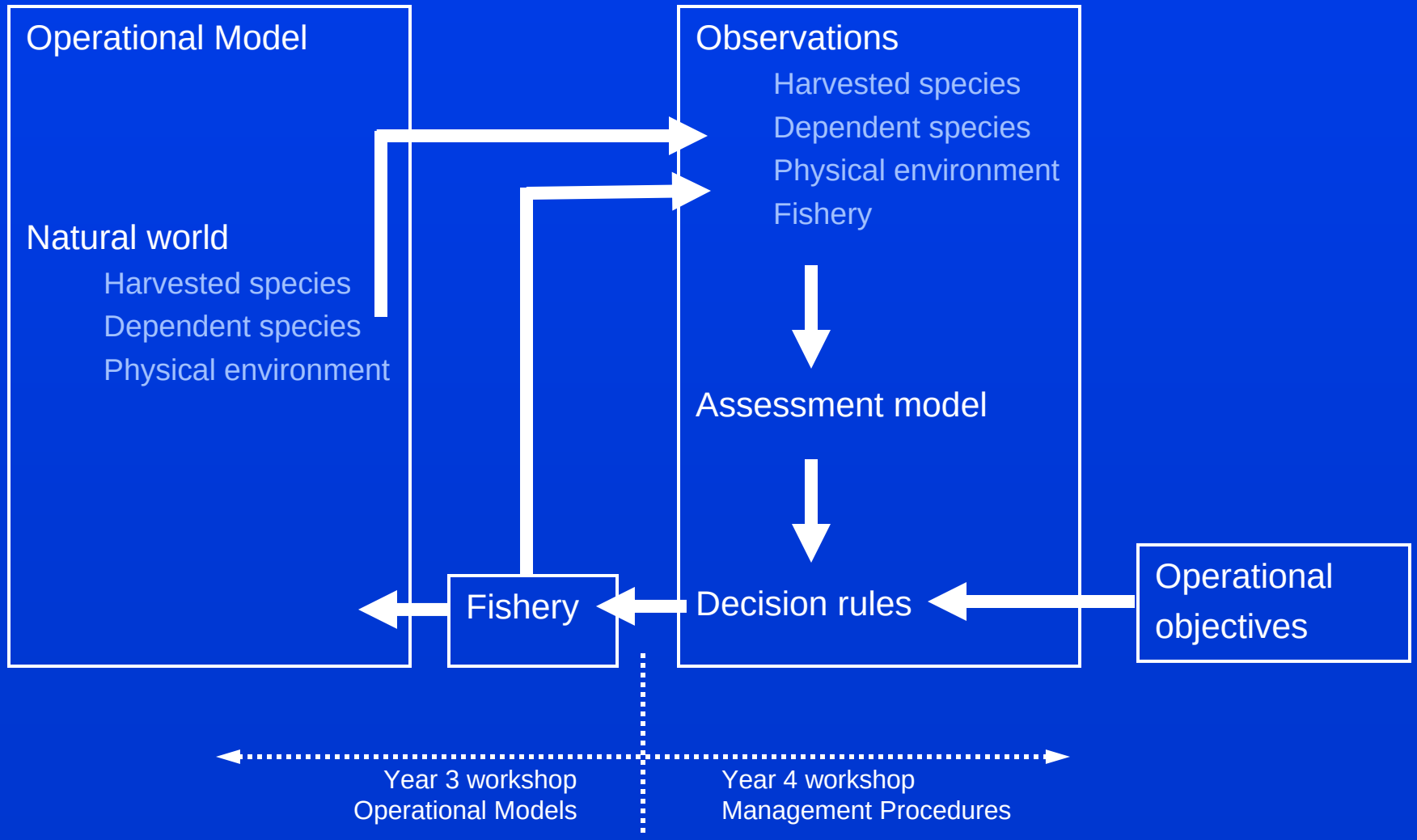
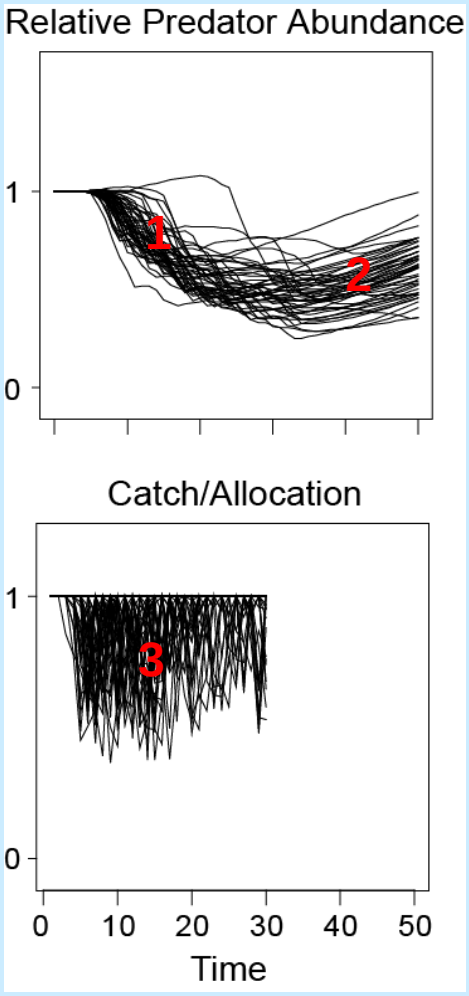
Evaluation of management procedures



Performance Measures



1. Probability that predators are depleted below a threshold and have a status based on generation times (e.g., “vulnerable” & “endangered”)

2. Probability that predators recover to a threshold after cessation of fishing and improve their status (e.g., endangered to vulnerable)

3. Means and variances of catch/allocation and change (relative to historical patterns) in the spatial distribution of catch

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Window of opportunity

- Human demand for krill resource is relatively low
- Establish a feedback management procedure based on ecosystem monitoring
- Fishery will develop in reaction to established management scheme rather than the reverse

- May never be possible to completely specify the system or even describe the true variability of system components
- More realistic to identify critical processes and elaborate a set of decision rules based on process indicators

Ecosystem monitoring and management strategy

- Define management objectives
  - Viability of krill population, adequate prey for krill predators
  - Ecosystem stability, diversity, target population levels
- Identify critical processes
  - Those that control krill recruitment and transport, predator population growth
  - Those that control larval transport/survival, habitat extent/quality, technological/economic development
- Define proxies for indexing processes and determine their statistical behavior
  - Sea ice extent, zooplankton constituents, predator reproductive performance and juvenile survival
- Elaborate management actions triggered by critical values of process indices
  - TAC adjusted depending on expected recruitment of age-1 krill, as indexed by combination of environmental and biological factors
  - Distribution of fishing effort adjusted depending on availability of krill to predators, as indexed by hydrographic indicators of krill transport and measures of the timing and intensity of krill spawning
- Research and development
  - Monitor performance of management system
  - Reduce measurement uncertainty
  - Describe key processes, indices and their behavior
    (e.g. pelagic production in the spring, regulation of penguin population growth)

Key concepts

- Resource conservation laws (international agreements) are a product of political compromise and therefore purposefully vague
- Define management objectives in operational terms
- Engage policy and technical people in ***proactive*** dialogue

- Impractical to completely specify the structure and dynamics of an ecosystem
- Identify key processes and monitoring indices
- Elaborate management triggered by critical values of indices
- Test performance and refine