IMPROVING MANAGEMENT OF ATLANTIC SEA SCALLOPS THROUGH OPTIMAL ROTATION OF FISHING GROUNDS

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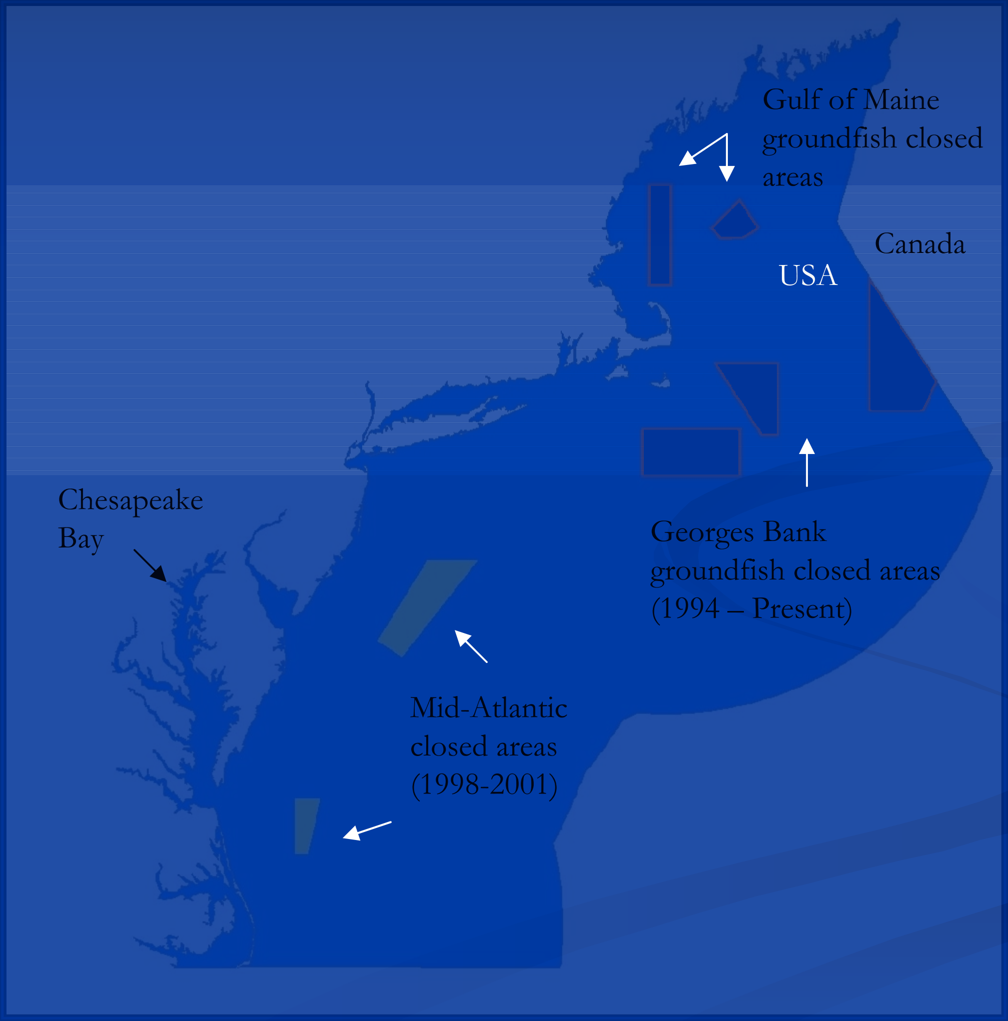
INTRODUCTION

- Atlantic sea scallops support the second most valuable fishery in the northeastern USA.
- Great variability in landings over the last 30 years.
- Dramatic declines in the 1990s, but the fishery has rebounded in the last few years.
- Demarcation of closed areas and effort-reduction measures have paid off – Unusual strong recruitment in recent years.

U.S. Landings and Average Ex-Vessel Price

Major Regions for Atlantic Sea Scallop Fishing



Landmarks of Sea Scallop Fishery Management in the EEZ

- 1982: Atlantic Sea Scallop Fishery Management Plan.
  - Minimum average meat weight.
- 1994: Amendment # 4.
  - Effort control measures (DAS, ring size, crew limits).
  - Closure of areas in GB and MAB.
  - Controlled-access programs to closed areas.
- 2004: Amendment # 10.
  - Spatially-based management system.

Mechanical Area Rotation Strategy Proposed by Amendment #10 (via FA 16)

Fishing Year	Closed Area I	Closed Area II	Nantucket Lightship Area
2004	Closed	0.2 (18%)	0.2 (18%)
2005	0.2 (18%)	0.2 (18%)	Closed
2006	0.2 (18%)	Closed	0.2 (18%)
2007	Same as 2004	Same as 2004	Same as 2004

$F = 0.2$ is the continuous fishing mortality that maximizes Yield-per-Recruit, or F_{Max}.

THE PROBLEM

Given the success of the controlled-access programs to closed areas, questions arise regarding optimal management strategies for the resource.

- Continuous fishing at $F_{Max} = 0.20$?
- Rotational harvesting? What would be the optimal cycle length? Optimal exploitation levels?
- A combination of both strategies?

OUR APPROACH

- Plenty of information is available on Atlantic sea scallops - New England Fisheries Management Council.
    - Life history is well known for the two most important stocks: Georges Bank and the Mid-Atlantic.
    - Efficiency of fishing gear has been studied extensively - Predator/Prey Theory.
    - Economic studies on costs of fishing for scallops.

- Integrate this information in a bioeconomic model to formulate optimal management strategies.

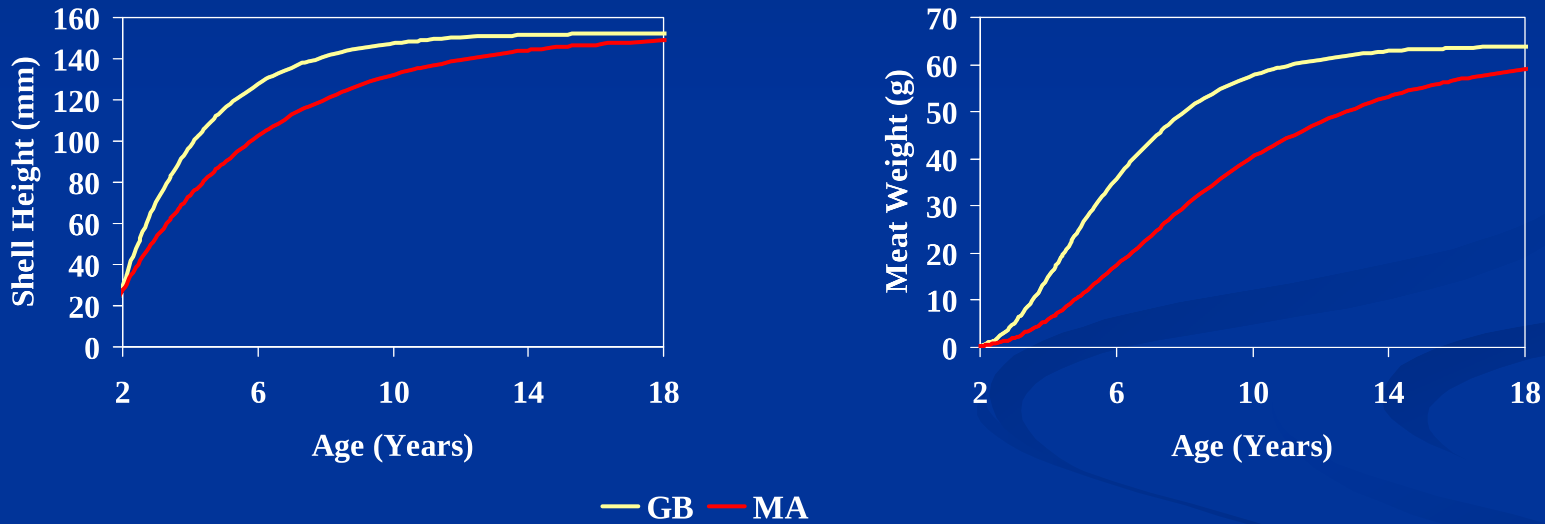
THE POPULATION SIMULATION MODEL

- Age-structured models were built within MATLAB to describe population dynamics in GB and the MAB.
- Population dynamics is driven by:
  - Natural recruitment.
  - Natural mortality.
  - Fishery exploitation.
- The model tracks biomass of scallops for plots of a given size located in Georges Bank and the Mid-Atlantic Bight, respectively. Captures are also monitored.

The Biology of Sea Scallops: Von Bertalanffy Growth Model

Shell Height

Meat Weight



$$s(t) = 152.5\,[1 - e^{(-0.4[t-1.45])}]$$ - GB

$$s(t) = 151.84\,[1 - e^{(-0.23[t-1.13])}]$$ - MA

$\mathbf{h}(t_k) = [I - e^{(\Delta t H(t_k))}]\,\mathbf{p}(t_k)$

The Biology of Sea Scallops: Vulnerability to Fishing Gear

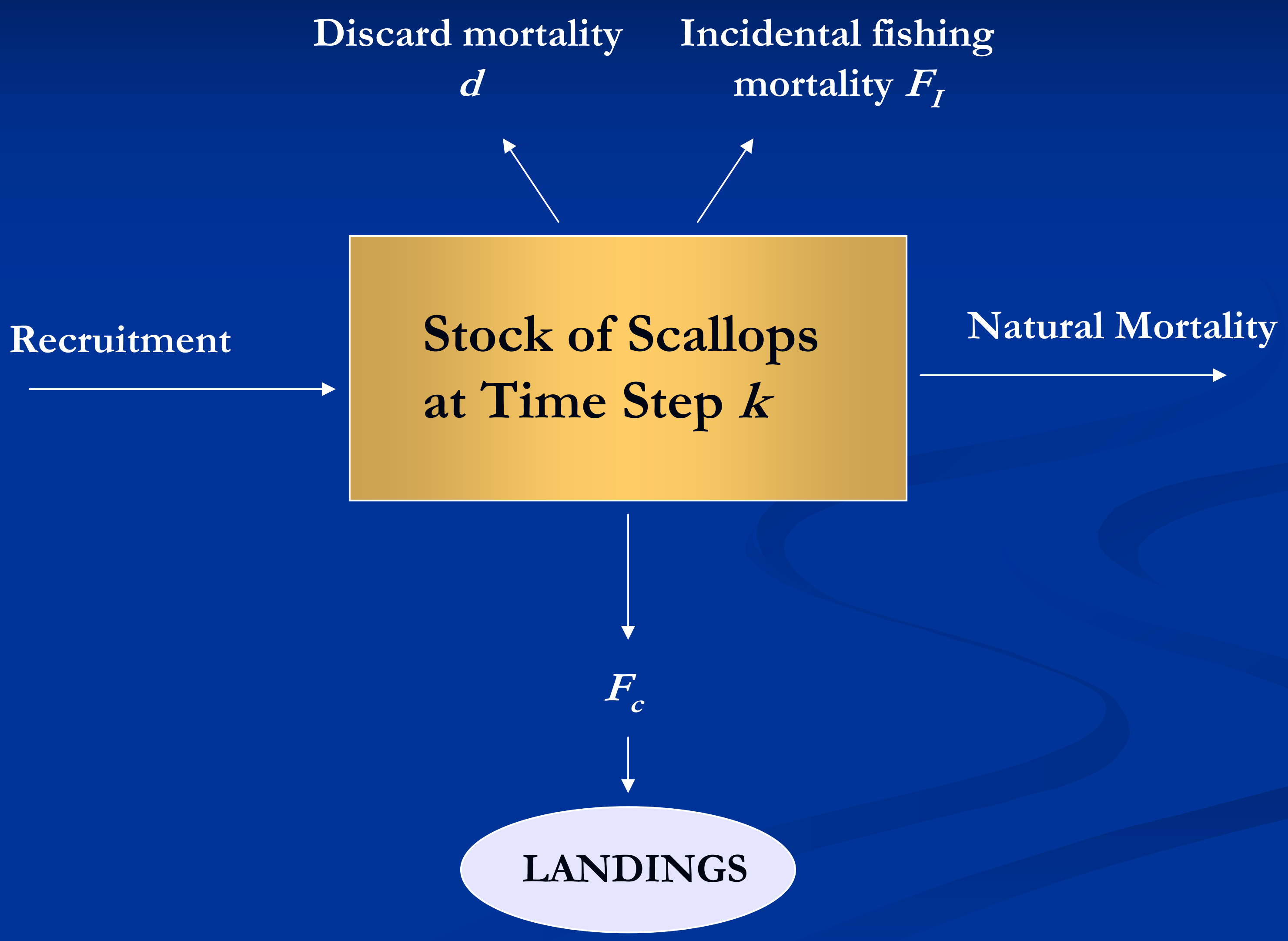
Catches at each size class and at each time step can be modeled as

$$\mathbf{h}(t_k) = [I - e^{(\Delta t H(t_k))}]\,\mathbf{p}(t_k)$$

where H is a diagonal matrix whose j^{th} diagonal entry h_{jj} is given by

$$h_{jj} = \begin{cases} 0 & \text{if } s(j) \le s_{\min} \\ -F_c(t_k)\dfrac{[s(j) - s_{\min}]}{(s_{full} - s_{\min})} & \text{if } s_d < s(j) < s_{full} \\ -F_c(t_k) & \text{if } s(j) \ge s_{full} \end{cases}$$

The Biology of Sea Scallops: Summary

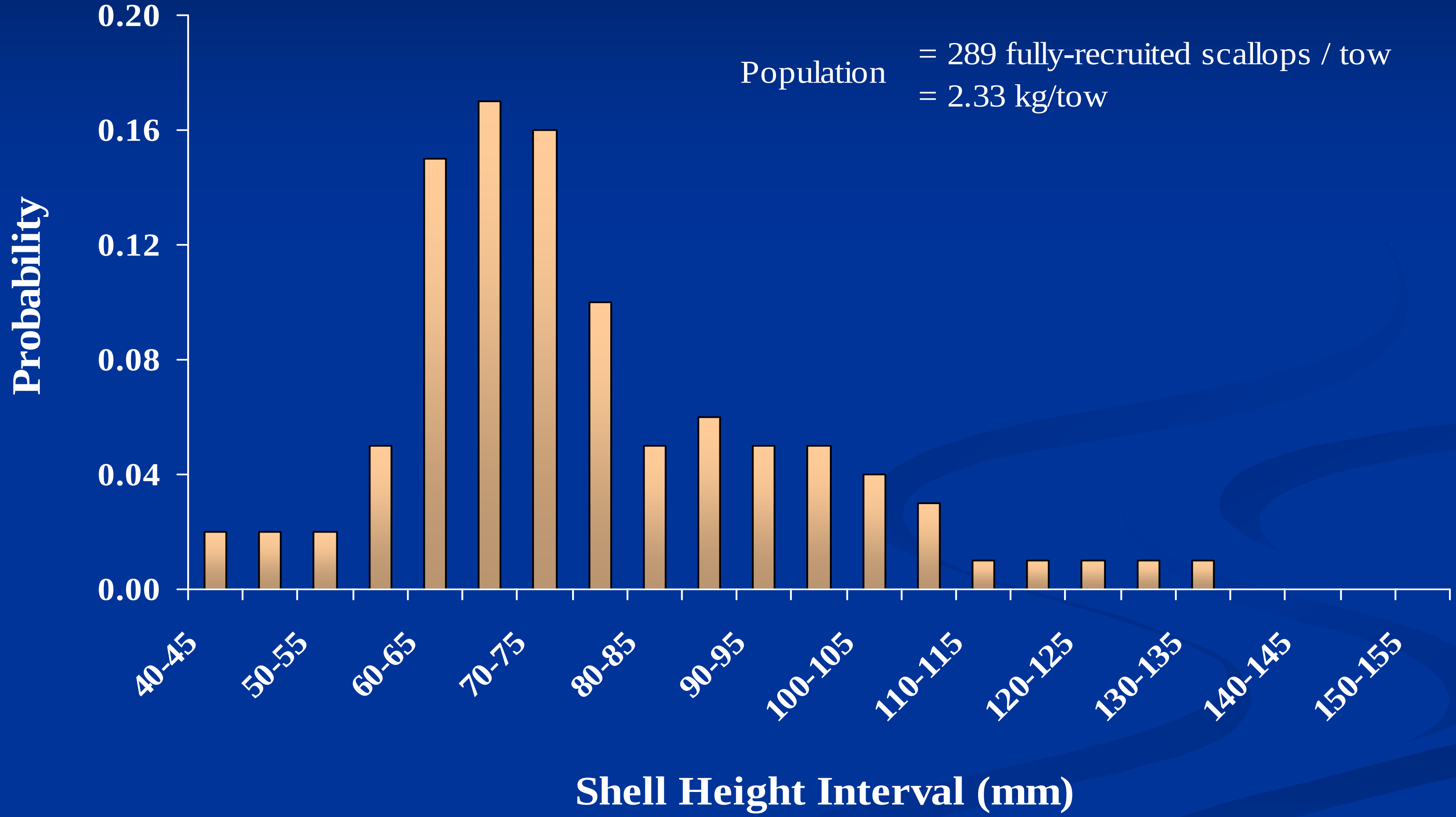


Parameters of the Age-Structured Model

Parameter	Description	Value
Δt	Simulation time step	0.083 years
L_∞	Maximum shell height	152.46 mm (GB), 151.84 (MAB)
K	Growth parameter	0.4 y^{-1} (GB), 0.23 y^{-1} (MAB)
m	Natural mortality rate	0.1 y^{-1} across all size classes
R	Annual number of recruits per tow	129 y^{-1} (GB), 58 y^{-1} (MAB)
a	Shell height/meat weight parameter	-11.6038 (GB), -12.2484 (MAB)
b	Shell height/meat weight parameter	3.1221 (GB), 3.2641 (MAB)
s_0	Initial shell height of recruit	40 mm
s_{min}	Minimum size retained by gear	65 mm
s_{full}	Size for full retention by gear	88 mm
s_d	Maximum size discarded	80 mm
d	Mortality of discards	0.2
e	Dredge efficiency	0.5 (GB), 0.7 (MAB)
α	LPUE/biomass relationship (seven-man crew)	49,056
β	LPUE/biomass relationship (seven-man crew)	102.8

Source: Northeast Fisheries Science Center (2001)

Initial Conditions



Data reflect shell height composition for Closed Area I (Georges Bank) in 1990.

Source: NEFSC (2001).

Economic Component : Prices

1996 Constant Ex-vessel Prices – Average of Historical Time Series

Size category	Price ($/lb)
Under 10	5.91
11-20	4.69
21-30	4.36
31-40	4.27
41-50	4.05
51-60	3.80
61+	3.65

Source: NEFSC (2004).

Economic Component: Costs

- Per-vessel annual operating costs in 1996 constant prices were estimated using an equation developed by Gautam and Kitts (1996).

$$Log\,(OPC) = \underset{(6.31)}{4.61} + \underset{(3.34)}{0.25}*Log\,(CREW) + \underset{(3.46)}{0.27}*Log\,(GRT) + \underset{(8.79)}{1.11}*Log\,(DAS)$$

t-value in parentheses.

where OPC = annual operating costs in 1996 constant prices;

CREW = vessel crew size;

GRT = vessel size in gross tons;

DAS = vessel days at sea.

Framing the Model as a Constrained-Optimization Problem

- The fishery manager sets a target level of fishing pressure F_T.
  - $F_T = F_c + F_I$
- Fishing fleet: 20 vessels operating in 680 nm^2.
- Goal of the Model: to maximize NPV_{30} of the fishery by choosing optimal levels of fishery exploitation (F_T) for each year.
- Constraint: F_T is allowed to fluctuate only between zero and 1.

Results of the Simulation Model - Georges Bank

Year	F_T	Year	F_T	Year	F_T	Year	F_T
1	0	9	0	17	0	24	0
2	0	10	0	18	0	25	0
3	0	11	0	19	0	26	0
4	0	12	0	20	0	27	0
5	0	13	0	21	0	28	0.527 (41%)
6	0.268 (24%)	14	0.074 (7%)	22	1 (64%)	29	1 (64%)
7	1 (64%)	15	1 (64%)	23	1 (64%)	30	1 (64%)
8	1 (64%)	16	1 (64%)				

Fishery is closed

Fishery is reopened after five years of closure

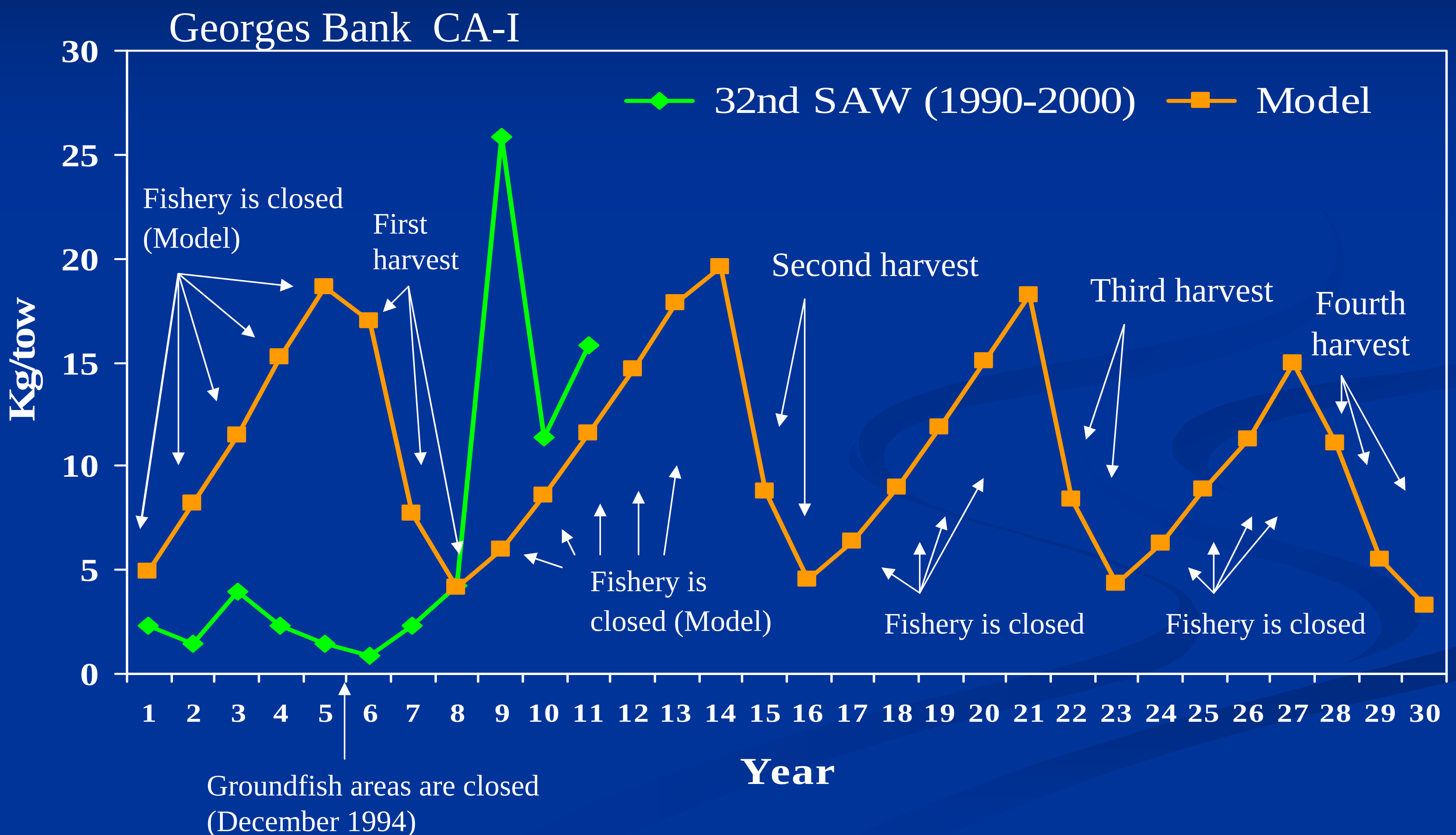
Results of the Simulation Model - Mid-Atlantic Bight

Fishery is closed

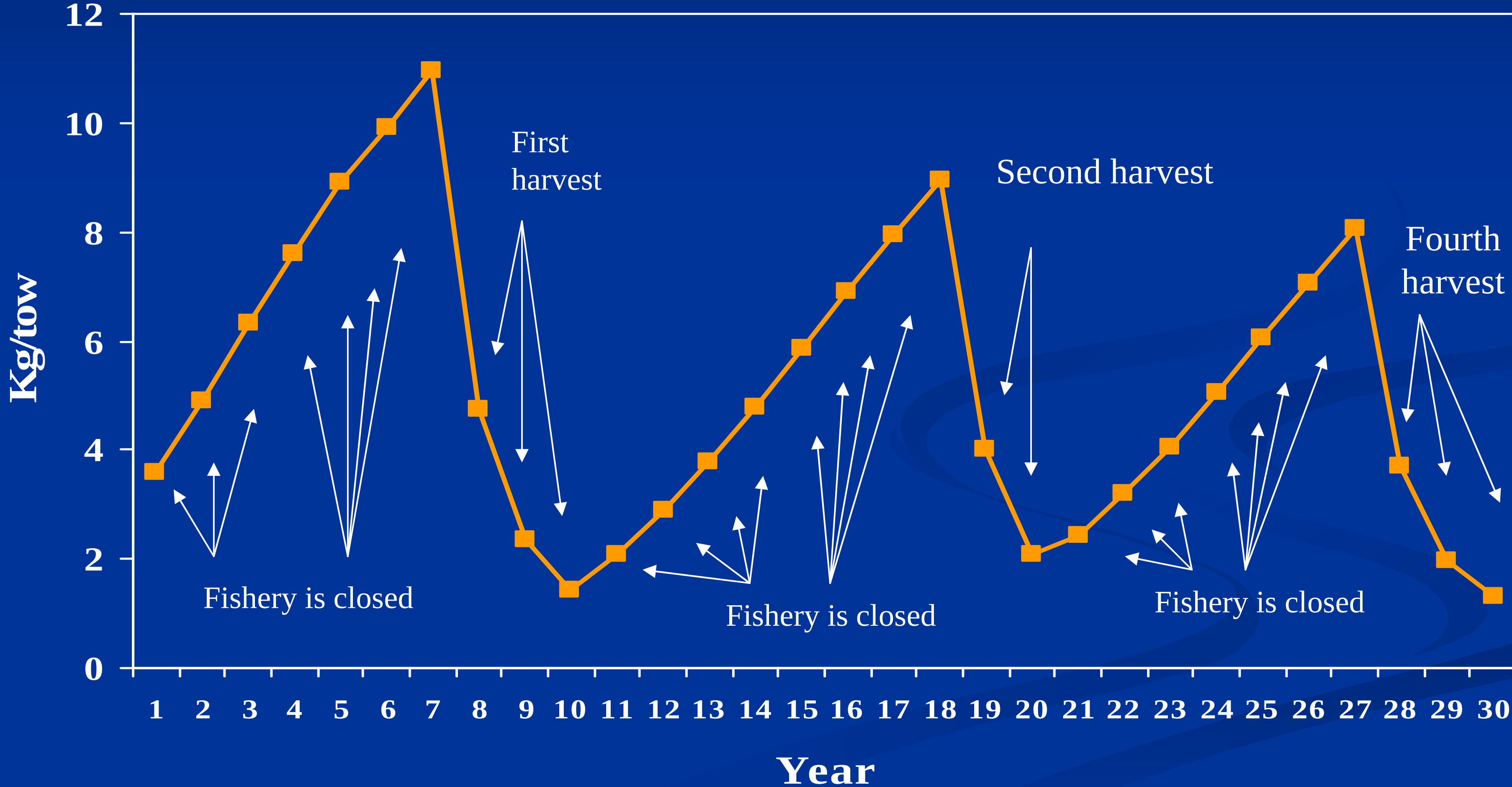
Year	F_T	Year	F_T	Year	F_T
1	0	11	0	21	0.145 (13%)
2	0	12	0	22	0
3	0	13	0	23	0
4	0	14	0	24	0
5	0	15	0	25	0
6	0	16	0	26	0
7	0	17	0	27	0
8	1 (64%)	18	0	28	1 (64%)
9	1 (64%)	19	1 (64%)	29	1 (64%)
10	1 (64%)	20	1 (64%)	30	1 (64%)

Fishery is reopened after seven years of closure

Biomass at the End of the Year
32nd SAW (1990-2000) vs. Model



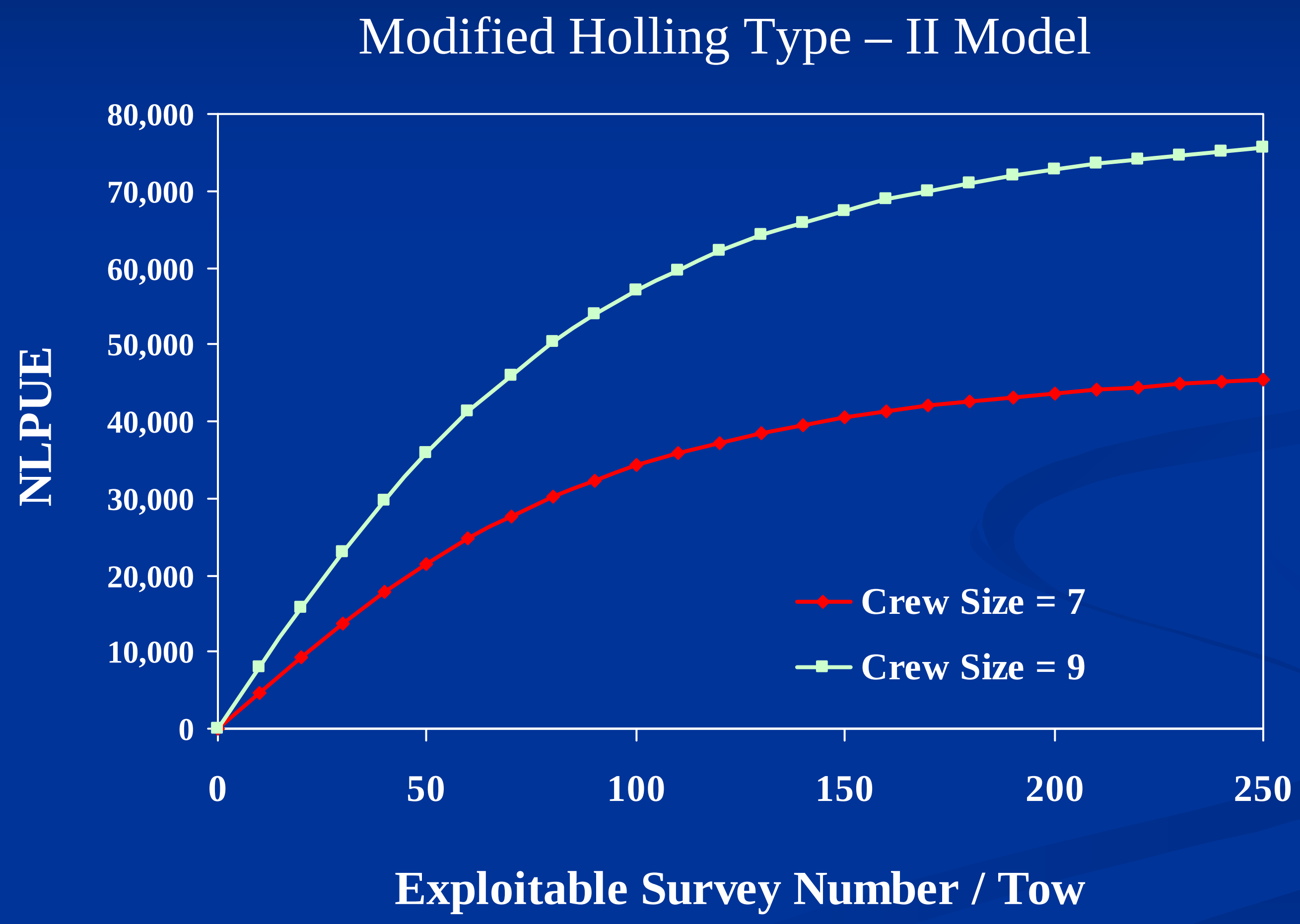
Biomass at the End of the Year
Mid-Atlantic Bight Region



Why is Rotational Harvesting Selected?

- Biological characteristics of the resource.
  - Rapid growth of biomass during the first years.
  - Low natural mortality.
  - Low mobility.
- Price premiums for larger scallops.
- Closures lead to higher LPUE upon re-opening of grounds, resulting in reduced operational costs.

Relationship between Exploitable Biomass and Landings per Unit of Effort



$$L = \frac{\alpha \ B}{\sqrt{\beta^2 + B^2}}$$

where *B* is exploitable biomass

How Does Optimal Rotation Compare to Other Management Strategies?

NPV_{30} (Million $)

Stock Area	Optimal Rotation	**$F_T = 0.2$, continuous**	Ramped rotation[a]
Georges Bank	324	278 (-14%)	294 (-9%)
Mid-Atlantic Bight	94	81 (-14%)	86 (-9%)

[a]This is a six-year rotation with F_T = 0, 0, 0, 0.32, 0.4, 0.48.

Results are robust with respect to variability in recruitment rates.

IMPLICATIONS

- Results of research are consistent with empirical evidence from Georges Bank and the Mid-Atlantic Bight.

- Re-opening of closed areas in 1999, 2001, and 2004 yielded extraordinary landings of very large scallops.

- Simple schemes of rotational harvesting with multi-year closure periods are the key for a more rational utilization of the resource.

- Optimal Cycles:
  - GB : 8 years (6 / 2).
  - MA : 10 years (8 / 2).

  Longer than current cycles considered by management authorities.