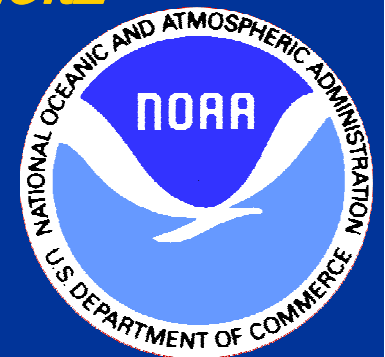


**The advantage of incorporating explicitly
predation mortality in stock assessment of
prey species (e.g. Atl.Herring and
Atl. Mackerel)**

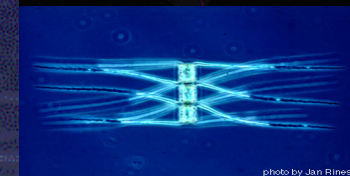
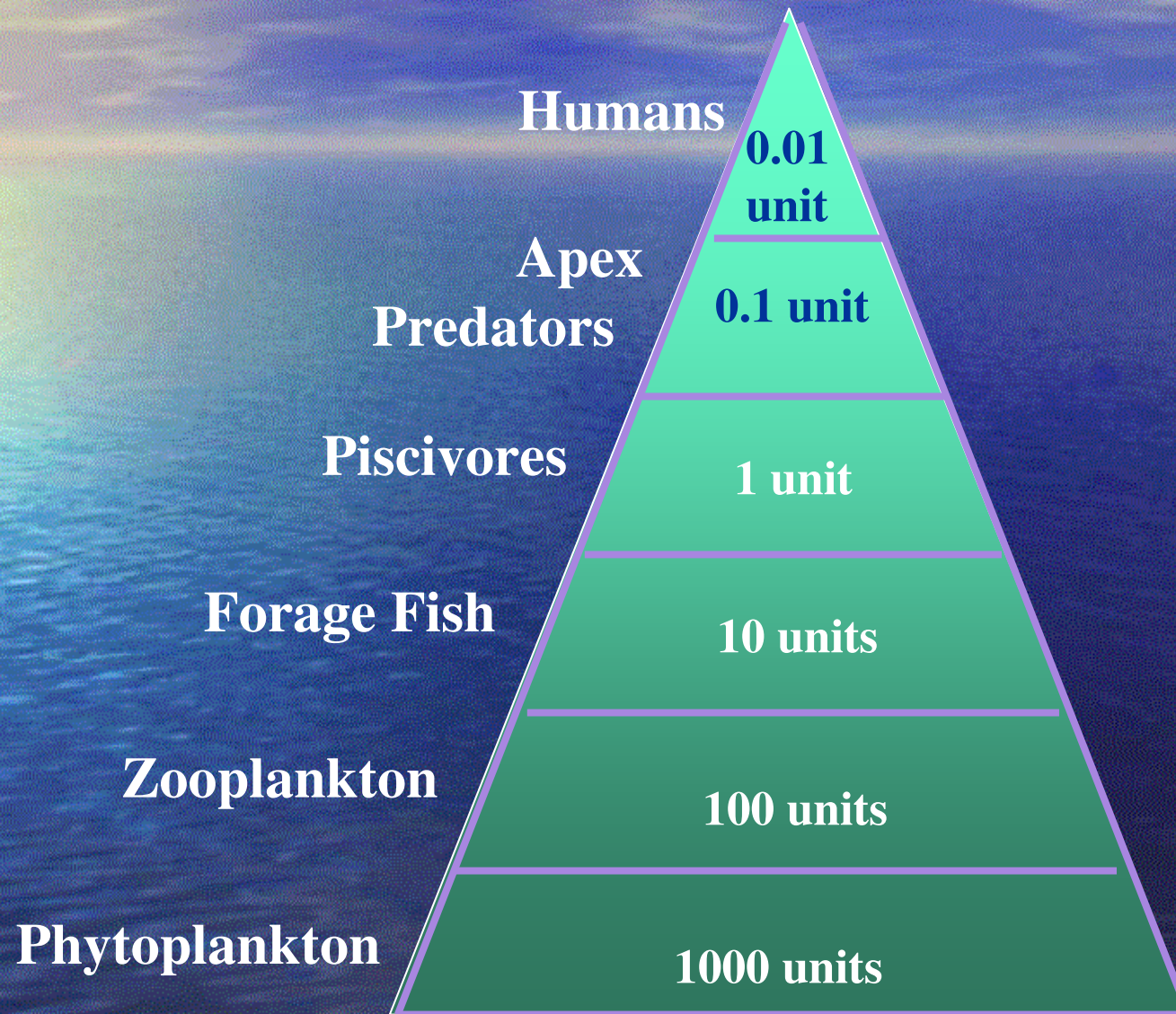
*By Hassan Moustahfid , William Overholtz
and Jason Link*

NOAA. Fisheries Service

*NORTHEAST FISHERIES SCIENCE CENTER
Woods Hole, MA, USA*



The Trophic Pyramid and Energy Flow

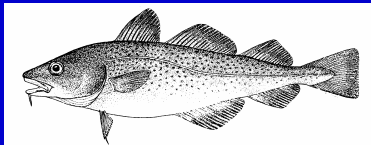


If transfer efficiency is 10%

Gradient of Possibilities



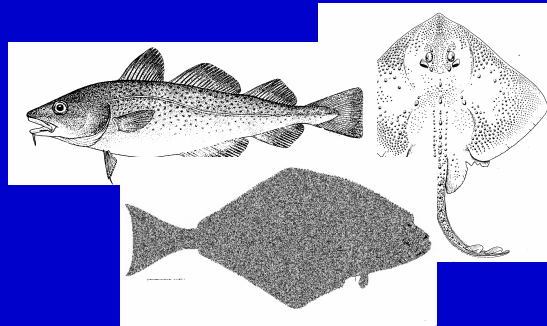
Stock/Single
Species



SS models, forget
ecosystem issues

Multiple SS
assessments
in "harmony"

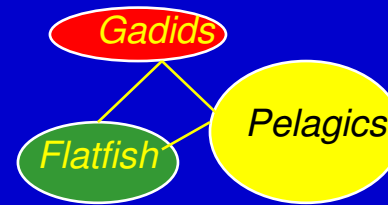
Multi-species



SS assessments
with explicit M2
or habitat or
climate
considerations

Multi-species
assessments

Aggregate
Biomass

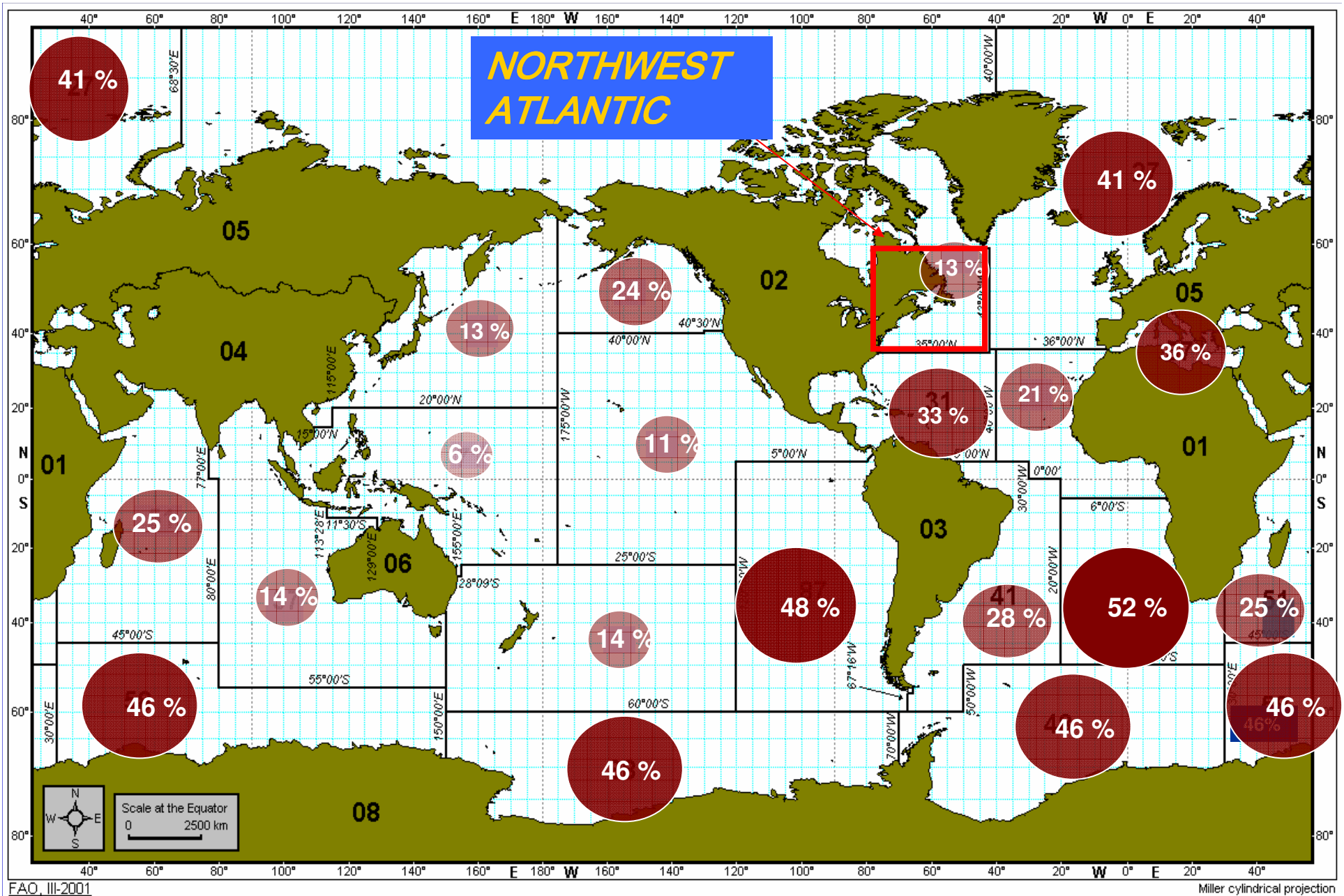


Aggregate
Biomass
Models

Ecosystem

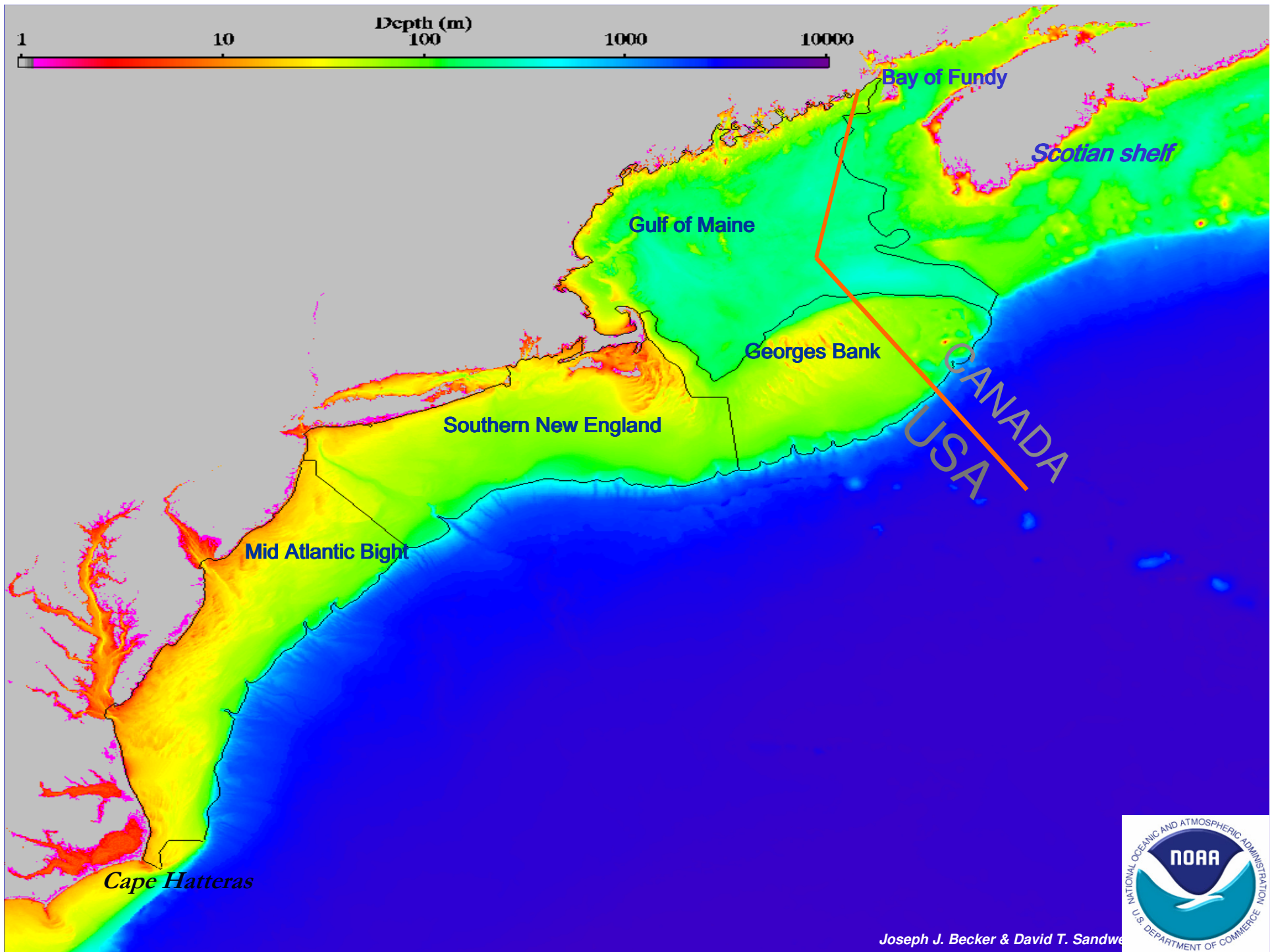
Messy
Picture
Here

Whole System
Models, forget
pop dy



Consequences of increasing Fishing effects : Nearly a third of the world's fish stocks are overfished, with the Atlantic the hardest hit.

2004 UN assessment



Joseph J. Becker & David T. Sandwe

- Pragmatic management of fisheries resources requires stock assessment advice that promotes yields that are sustainable in the long term
- To achieve this long-term sustainability stock assessment scientists must account for ecosystem considerations (e.g. changes in the physical and biological factors) to provide appropriate advice
- Shifts in predation mortality are one of the biological factors that can impact stock assessments.

Estimated annual loss of fish to predation in six marine ecosystems compare to fisheries removals

Ecosystems	Annual fish Loss (tonnes/km)			
	<i>Birds</i>	<i>Mammals</i>	<i>Fish</i>	<i>Fisheries</i>
<i>Benguela current</i>	0.3	2.6	56.5	1.6
<i>Georges Bank</i>	2.0	5.4	42.5	6.1
<i>Balsfjord</i>	0.0	0.0	14.1	1.5
<i>East Bering Sea</i>	0.2	1.5	11.0	1.4
<i>North Sea</i>	0.6	0.1	7.0	4.4
<i>Barents Sea</i>	0.0	3.0	5.1	1.8
<i>Data from Bax 1991.</i>				

Major predators of fish are the fish themselves.

Predation by man is substantially less, roughly the same level as marine mammals

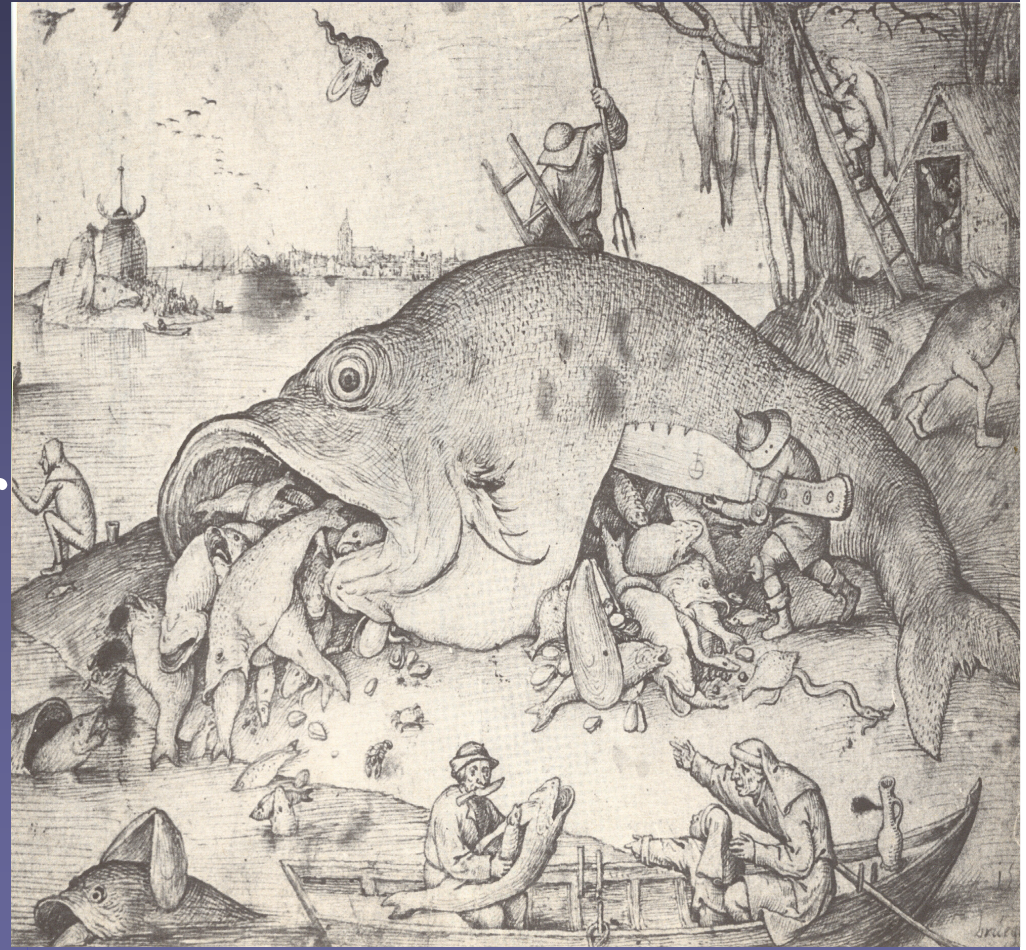
Predation represents an important process in the regulation of fish populations

- In most traditional stock assessment models, predation in the form of M is entered as a constant rate across time
- Incorporating explicitly predation in stock assessment models for prey species may improve stock assessment by rectifying estimates of M and should generate more realistic estimates of BRPs

- Predation can be incorporated using complex models such as MSVPA
(e.g. *Sparholt 1991; Tsou and Collie 2001; Tyrrell et al. 2008*)
- or simply by creating a new catch series of consumption by predators as an input into SS models (e.g. *Overholtz et al 2008; Moustahfid et al., in press*)

Fish food habits data to estimate Consumption

NEFSC Examined
Diet Composition of
over 500,000 (+ this
past year!) Individual
Fish comprising over
130 distinct species of
Predators and over
1300 distinct prey
taxa on the Northeast
Continental Shelf



Objectives

- *Estimate Predation Mortality (M2) on Herring and Mackerel*
- *Evaluate potential changes to model estimates and BRPs by including this Predation Mortality*
- *Determine the Impact of Predation on Herring and Mackerel Dynamics*
- *Quantify the Effect of Predation on Long-Term Yield Potential*



MM



Fishing



Smooth Dogfish



Spiny Dogfish



Winter Skate



Silver Hake



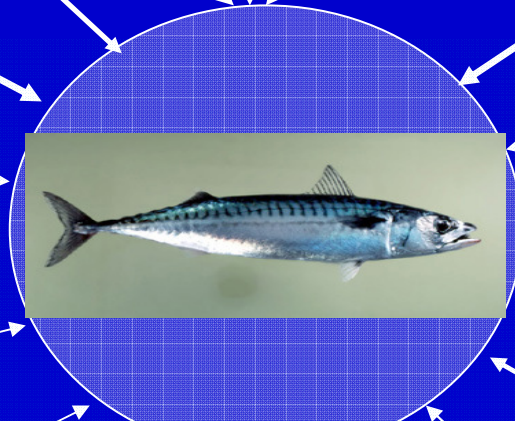
Red Hake



Bluefish



Atlantic Cod



Atlantic Mackerel



Weak fish



Pollock



Goosefish



Sea Raven



Fourspot Flounder



Summer Flounder

Computing Consumption Removal

$$C_{it} = 24 \cdot R_{it} \cdot \overline{S_{it}^{\gamma}} \cdot D_t \cdot N_{it} \cdot$$

S_{it} is the mean stomach content weight (g),

γ is a shape function assumed equal to 1 (Gerking 1994),

N_{it} is predator abundance

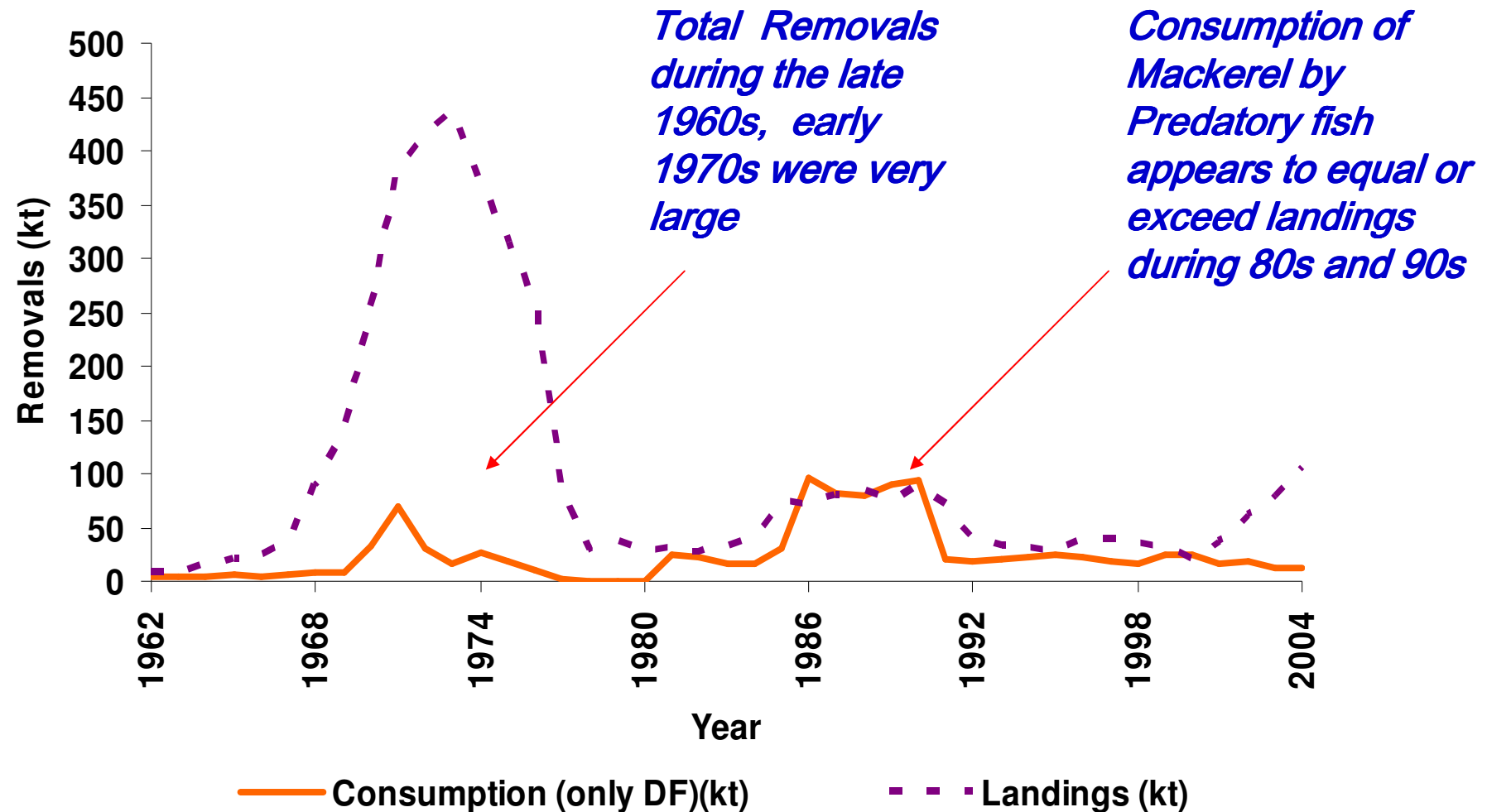
D_t is the number of day in a season

and R_{it} is the evacuation rate

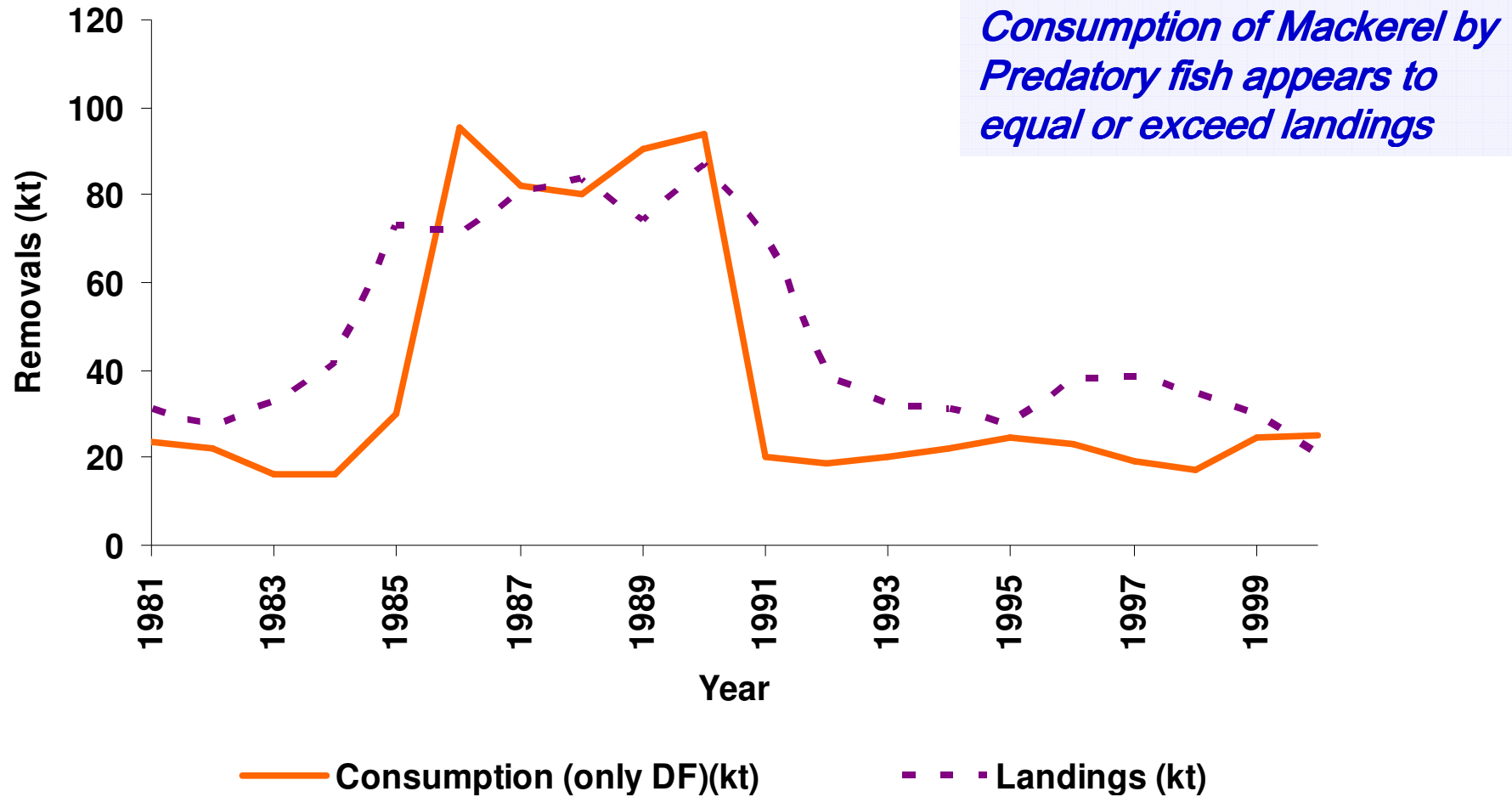
$$R_{it} = a e^{\beta T}$$

where a and β are fitted constants and T is seasonal bottom temperature ($^{\circ}\text{C}$)

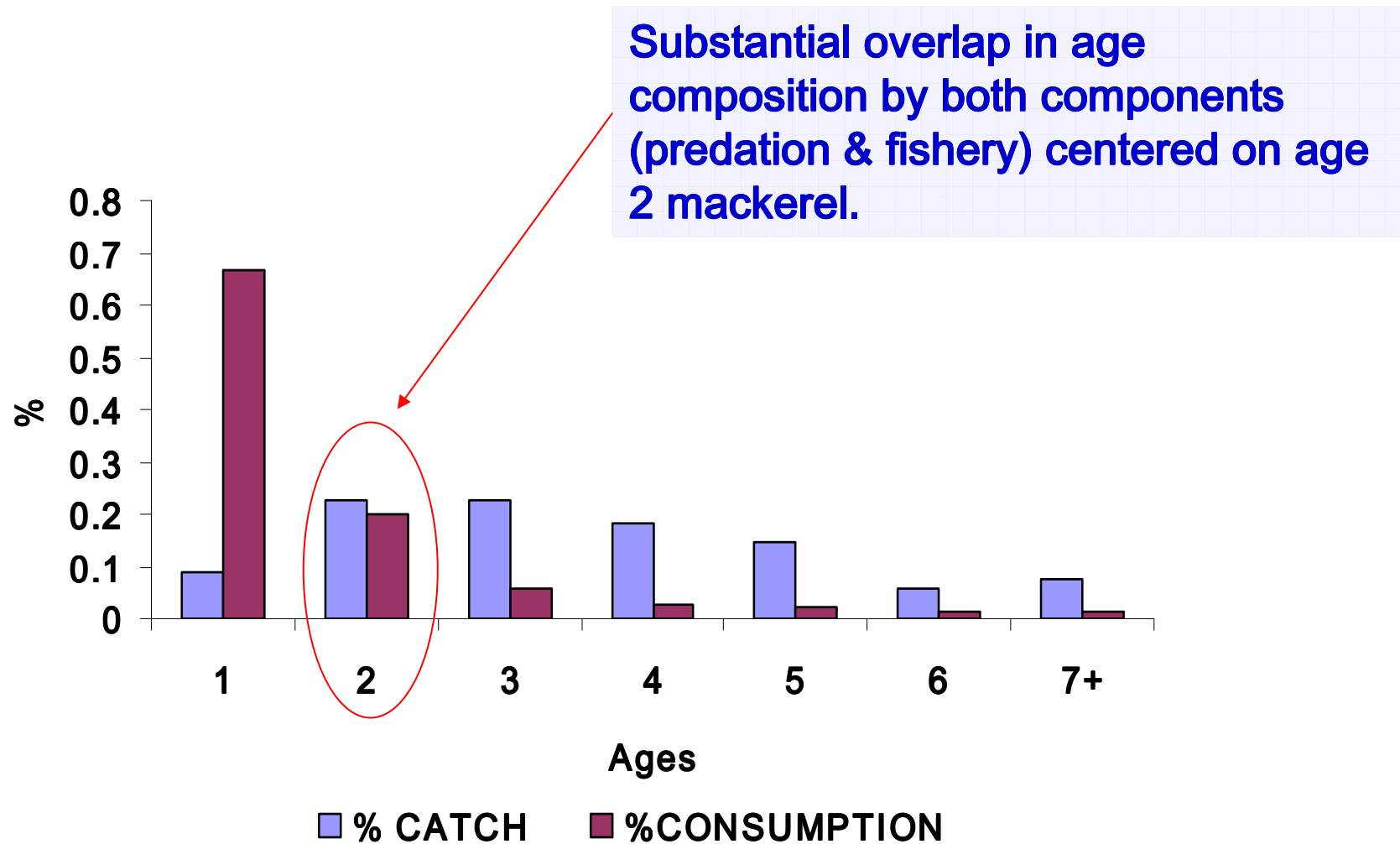
Estimated annual losses of Atl. Mackerel to Predation compare to Fisheries Removals in NAFO SA 2-6 (US-CANADA)



Estimated annual Predation removals of Atl. Mackerel compare to Fisheries removals



Age composition of mackerel in stomach of predators and in commercial fishery

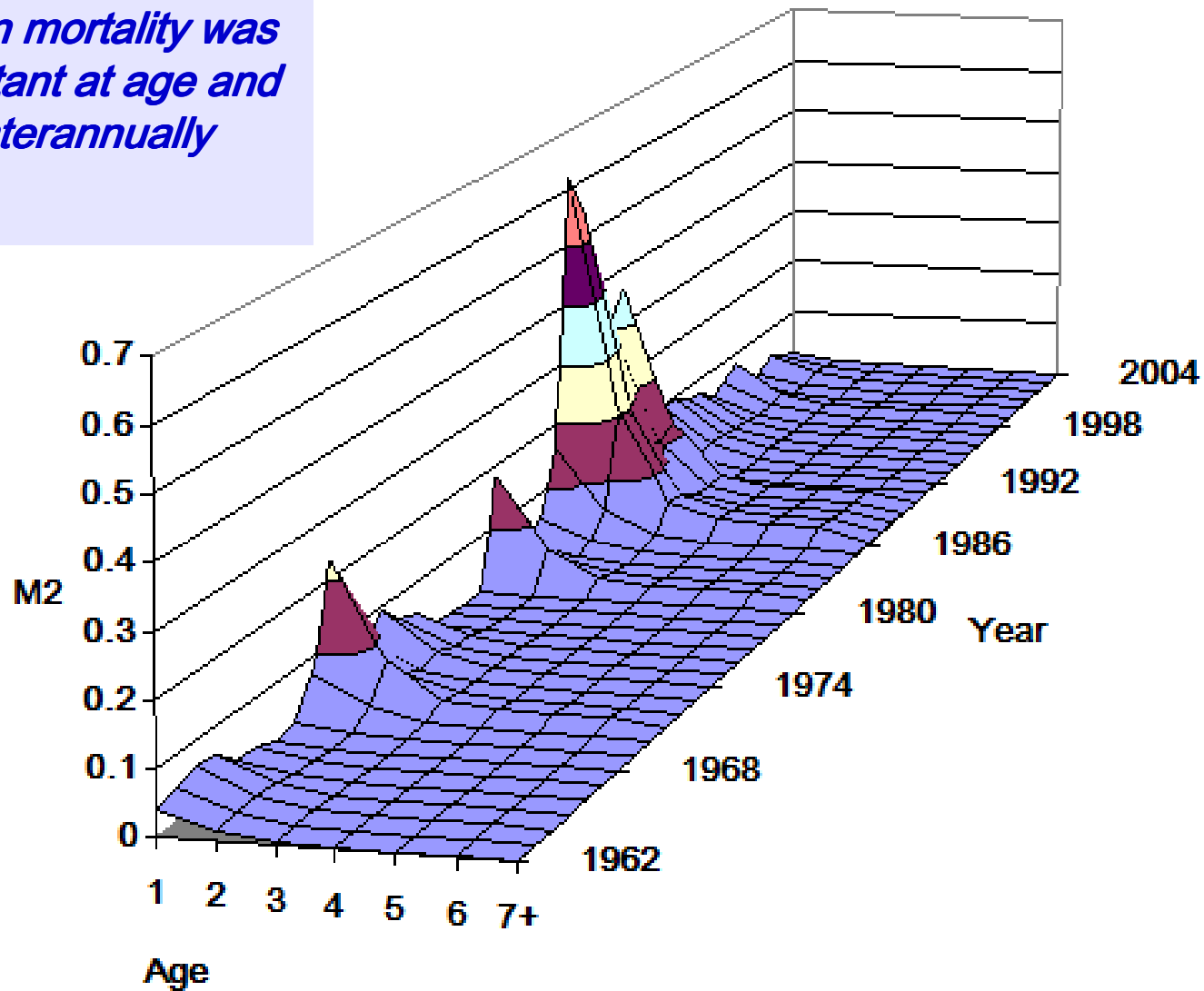


Incorporating predation in Stock Assessment of Atl. Mackerel

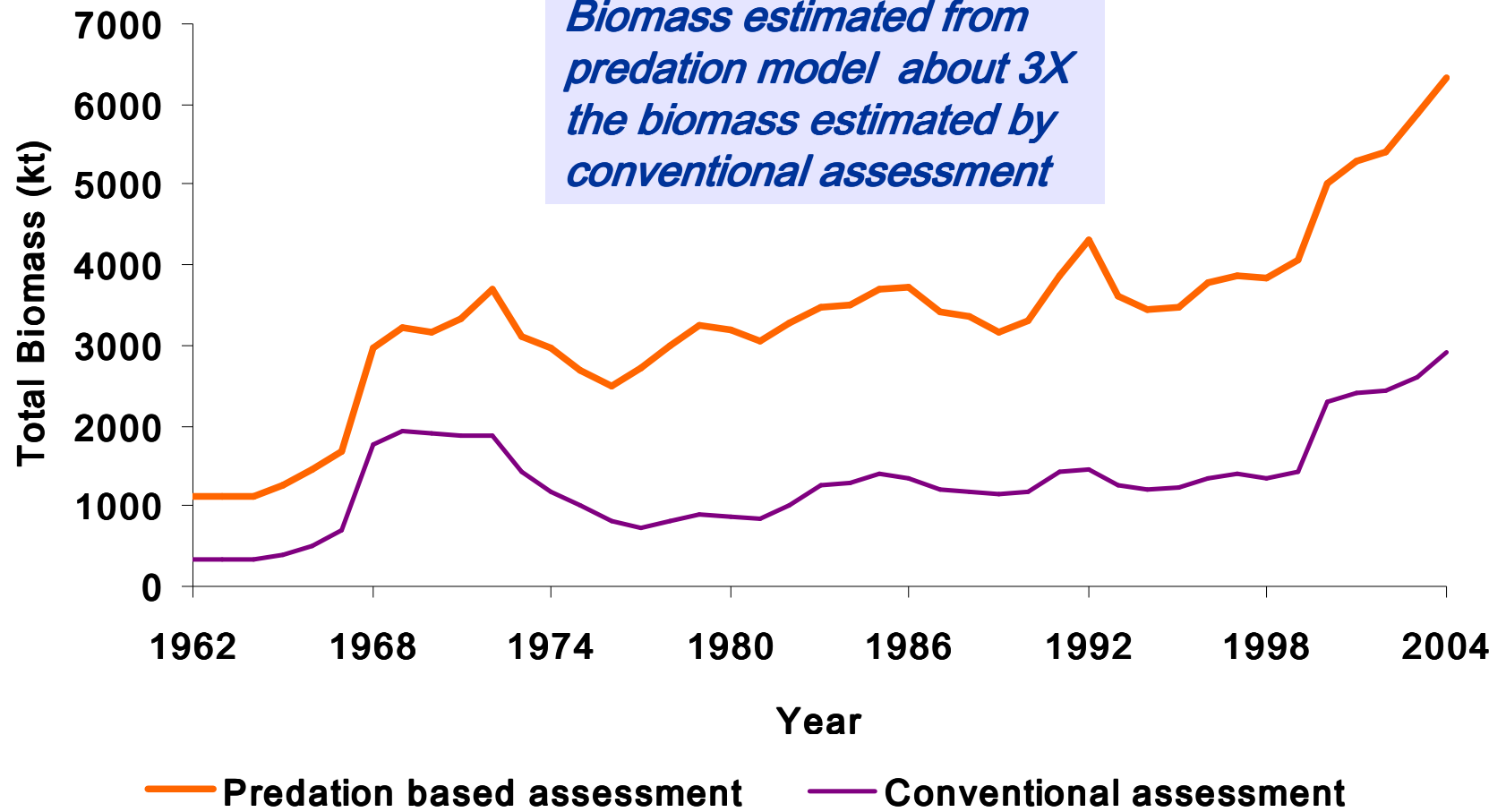
- Used An Age Structured Assessment Program (ASAP) from NOAA Fisheries Toolbox.
- Model Predation as additional fleet
- Incorporate Predation into Assessment Model
($Z=M1+M2+F$)

Predation mortality (M2)

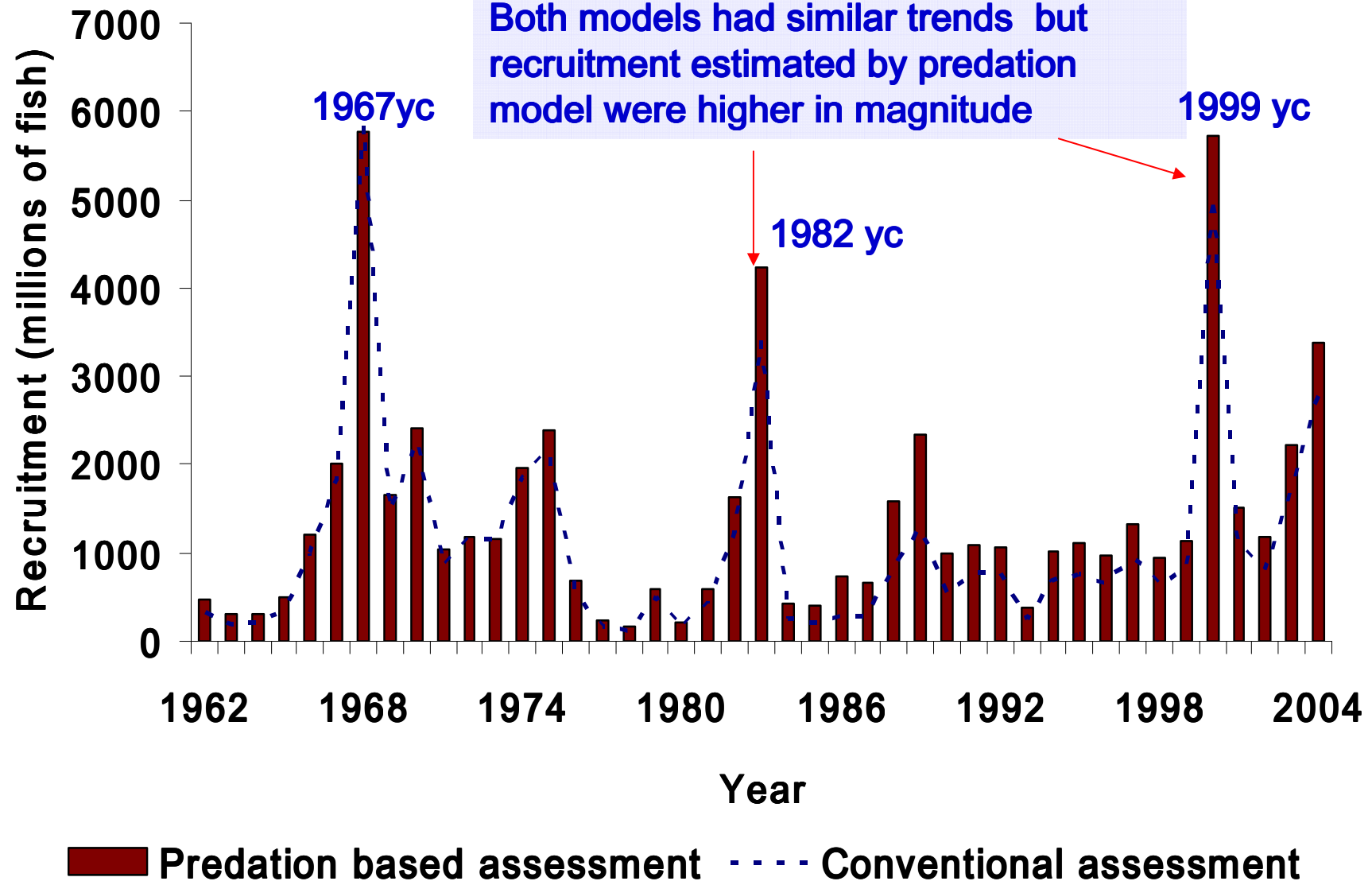
Predation mortality was not constant at age and varies interannually



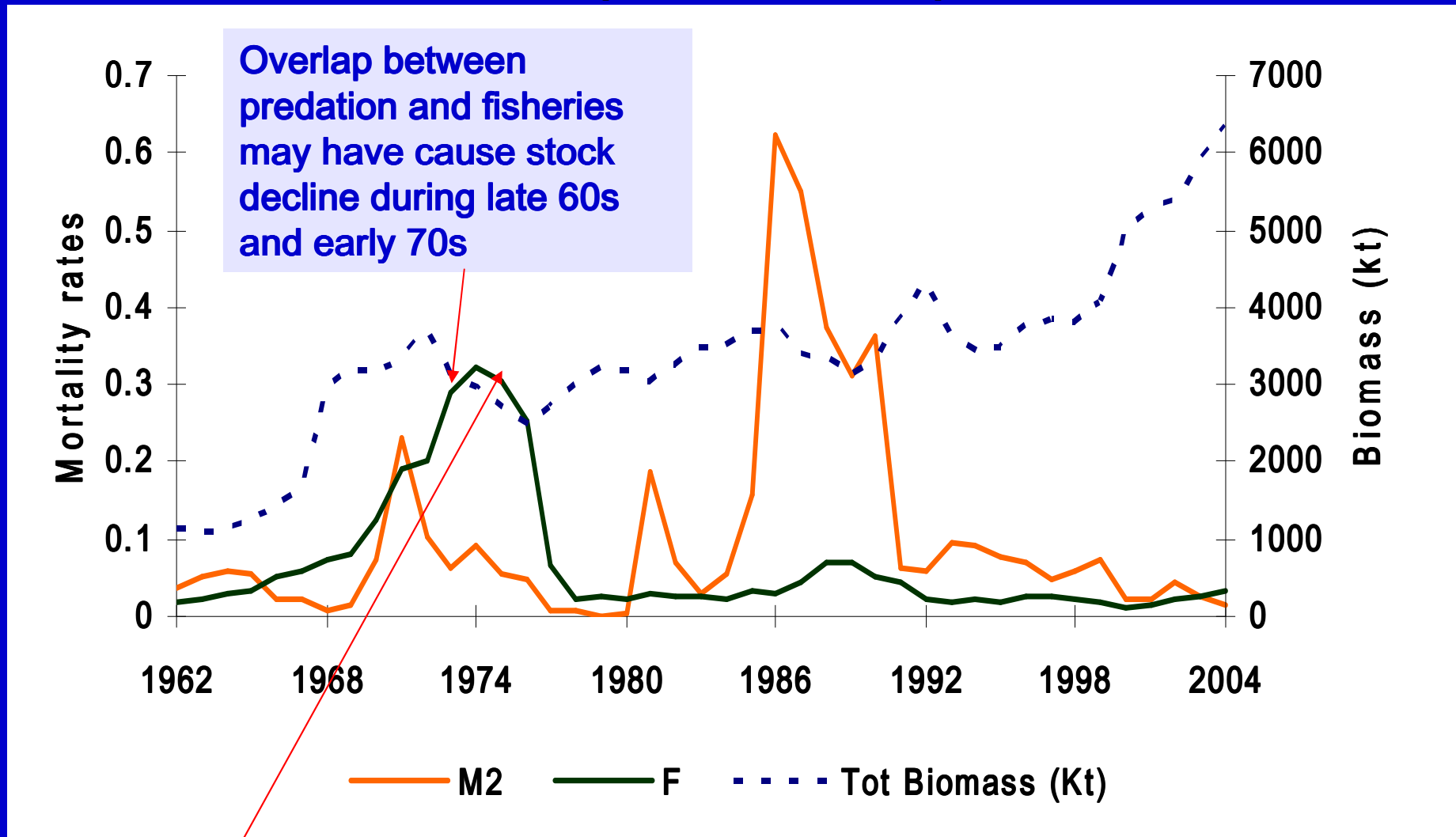
Total Biomass



Recruitment

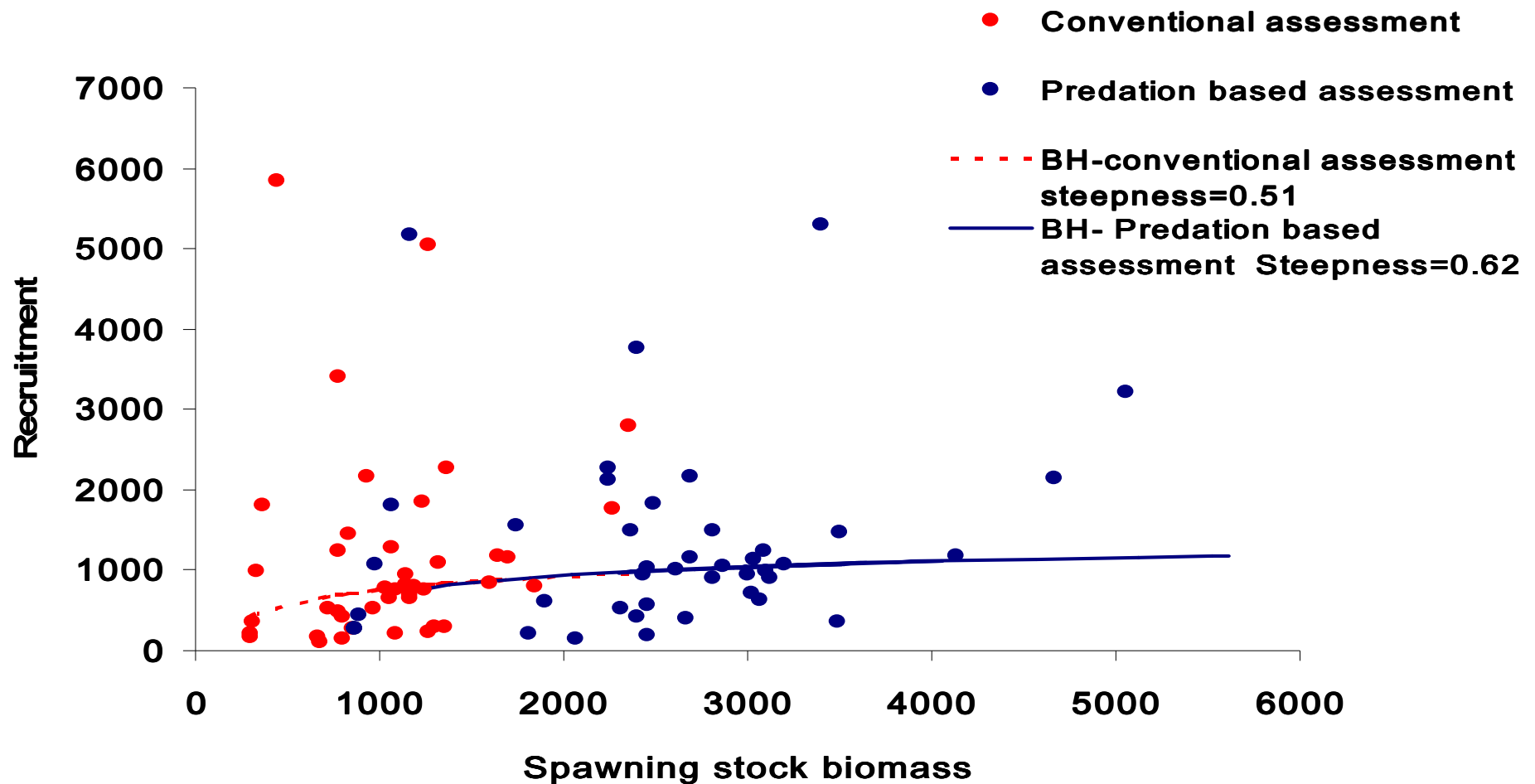


Total Biomass and Mortality rates (M2 and F)



Mackerel were heavily exploited by Distant Water Fleets during the late 60s-early 70s

Beverton-Holt stock-recruitment model



Adding predation to the model increased the estimated number of age-1 mackerel, which changed the apparent stock recruitment relationship from one with low recruitment compensation to one with high recruitment compensation

Long-Term Yield

<i>BRPs</i>	<i>Fishery only</i>	<i>BRPs</i>	<i>Predation included</i>
<i>MSY_f</i>	<i>89,000 (t)</i>	<i>MSY_{pf}</i>	<i>163,000 (t)</i>
<i>$BMSY_f$</i>	<i>644,000 (t)</i>	<i>$BMSY_{pf}$</i>	<i>1,745,000 (t)</i>
<i>$FMSY_f$</i>	<i>0.16</i>	<i>$FMSY_{pf}$</i>	<i>0.19</i>

BRPs such as BMSY estimated by Predation model 3X higher than BMSY estimated by Conventional model

BRPs derived from ASAP model (Legault and Restrepo, 1999) based on equilibrium conditions, per-recruit analyses, and a BH stock-recruitment relationship

Partition of Total Yield to Fishery Yield and Predator Demand

- Total yield = 163,000 t
- Yield for fishery = 68,000 t
- Predator demand = 95,000 t

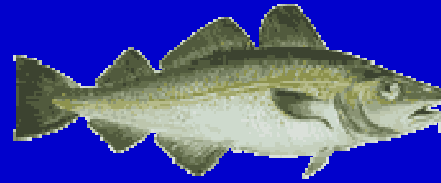
If predator biomass increase (because FMP Rebuilding Plan for Demersal fish stock and protected species) in the next several decades, then we will expect the Predator Demand to increase and Yield for fishery to decrease.

***Predator
Groups on
Atlantic Herring***

30 species



Herring



**Medium
Demersal Fish**



**Marine
Mammals**



Large Pelagic Fish



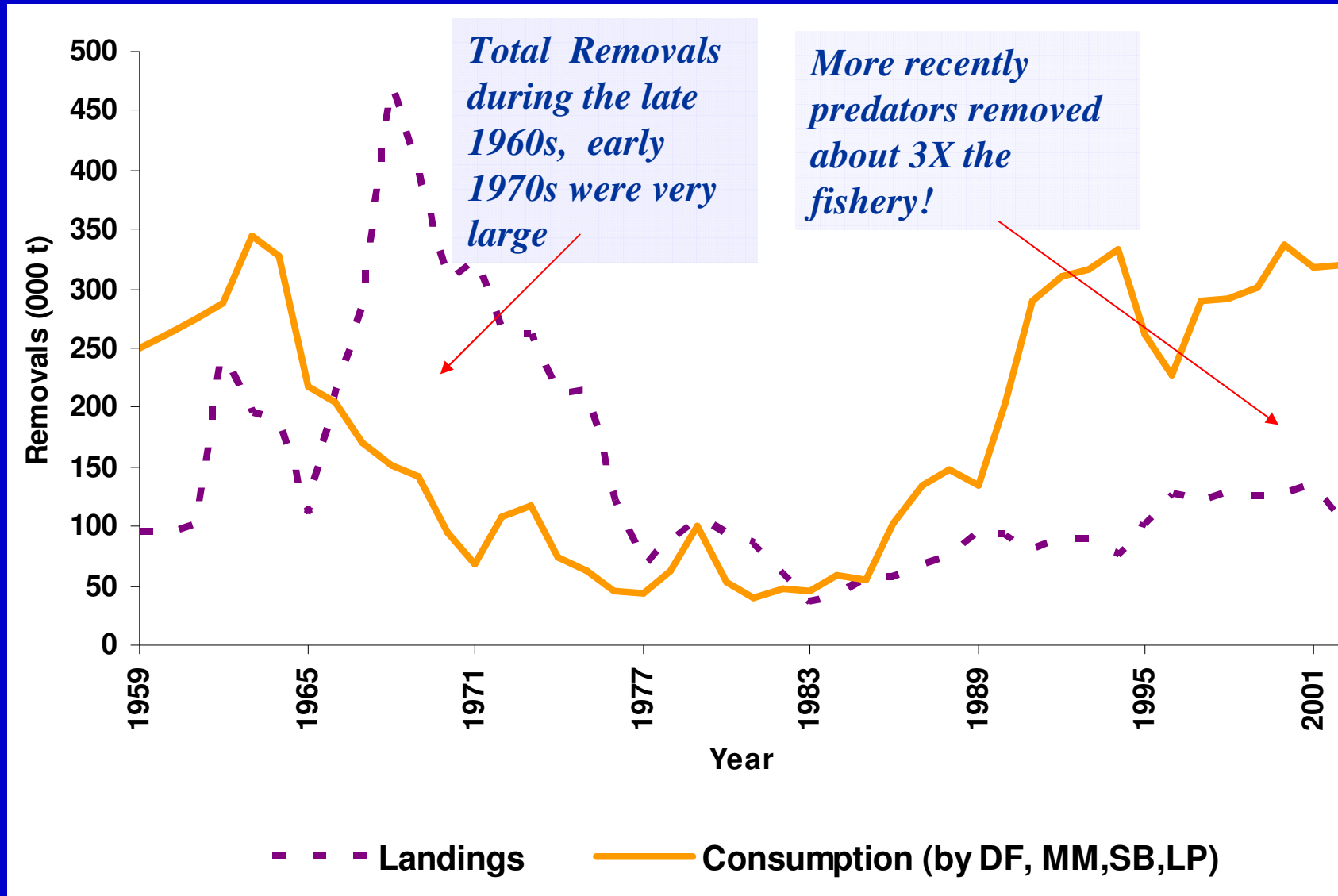
Herring Fishery



Seabirds

(Overholtz and Link , 2007)

Estimated annual losses of Atlantic Herring to Predation compared to Fisheries Removals



(Overholtz et al. 2008 in NAJFM)

An Ecosystem Assessment of Atlantic Herring

- *Incorporate Predation into Assessment Models ($Z=M1+M2+F$)*
- *Predation Model , Herring consumption data were treated in the same way as additional fleet*
- *Used delay-difference model*
- *Assess Impacts of Predators*
- *Predict Fishery Yield from Predator –Prey System*

Stock assessment for Herring

- was a biomass dynamic approach based on the Deriso-Shnute delay difference equation (Quinn and Deriso 1999)
- The model assumed that fishery catch and predator consumption were measured accurately and that herring ages 2+ were all equally available to the fishery and predators.
- Parameters were estimated by maximum likelihood and by fitting the model to a very wide range of fishery independent abundance indices and hydro-acoustic biomass data
- $Z = F + M1 + M2$ ($M1 = 0.05y^{-1}$)
- $f = F + M2$
- Catch equation $F = (L/C + L)f$
- $M2 = f - F$

SP

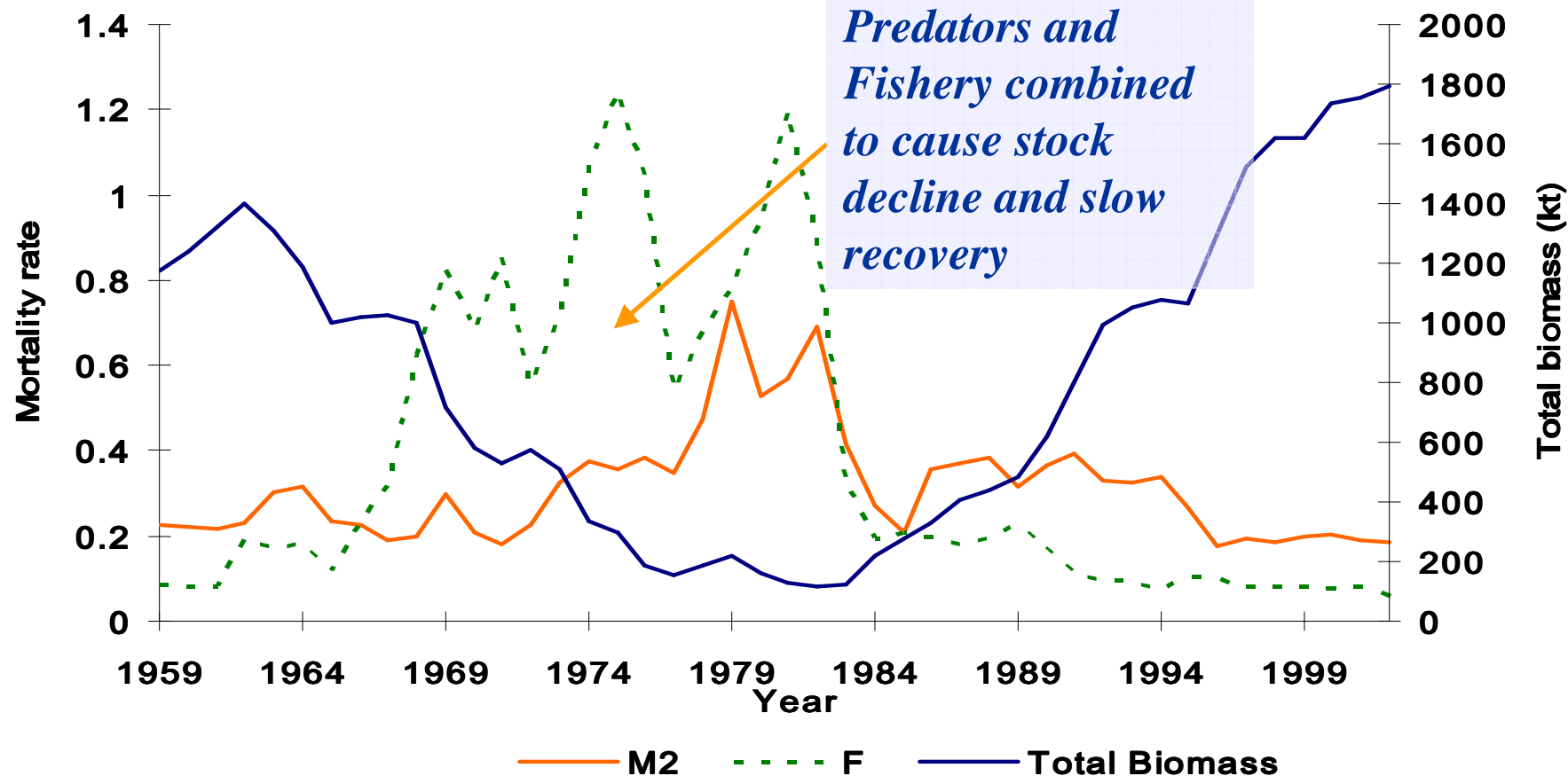
- Similar to Jacobson et al.'s 2002 “external” approach.

$SP_t = B_{t+1} - B_t$ assuming fishing and predation mortality rates were 0

$B_{t+1} = B_t \exp(G_t - M_2) + R_{t+1}$ G_t instantaneous rate for somatic growth in weight R_{t+1} recruitment biomass.

SP calculations were exact algebraically not based on the approximate formula

Herring Biomass and Mortality rates (M2 and F)



This suggests that high fishery-predator overlap may require careful attention to the potential for overfishing for GB and GOM Herring stock.

Long-Term Yield

<i>BRPs</i>	<i>Fishery only</i>	<i>BRPs</i>	<i>Predation included</i>
<i>MSY_f</i>	<i>222,000 (t)</i>	<i>MSY_{pf}</i>	<i>528,000 (t)</i>
<i>BMSY_f</i>	<i>896,000 (t)</i>	<i>BMSY_{pf}</i>	<i>1,452,000 (t)</i>
<i>FMSY_f</i>	<i>0.250</i>	<i>FMSY_{pf}</i>	<i>0.364</i>

Partition of Total yield To Fishery Yield and Predation Demand

■ *Empirical methods*

- Recent-consumption approach based on current estimate of total consumption.

$$Y_{fishery} = MSY_{pf} - PD$$

- Average-proportion approach estimated $Y_{fishery}$ using the average $M2$.

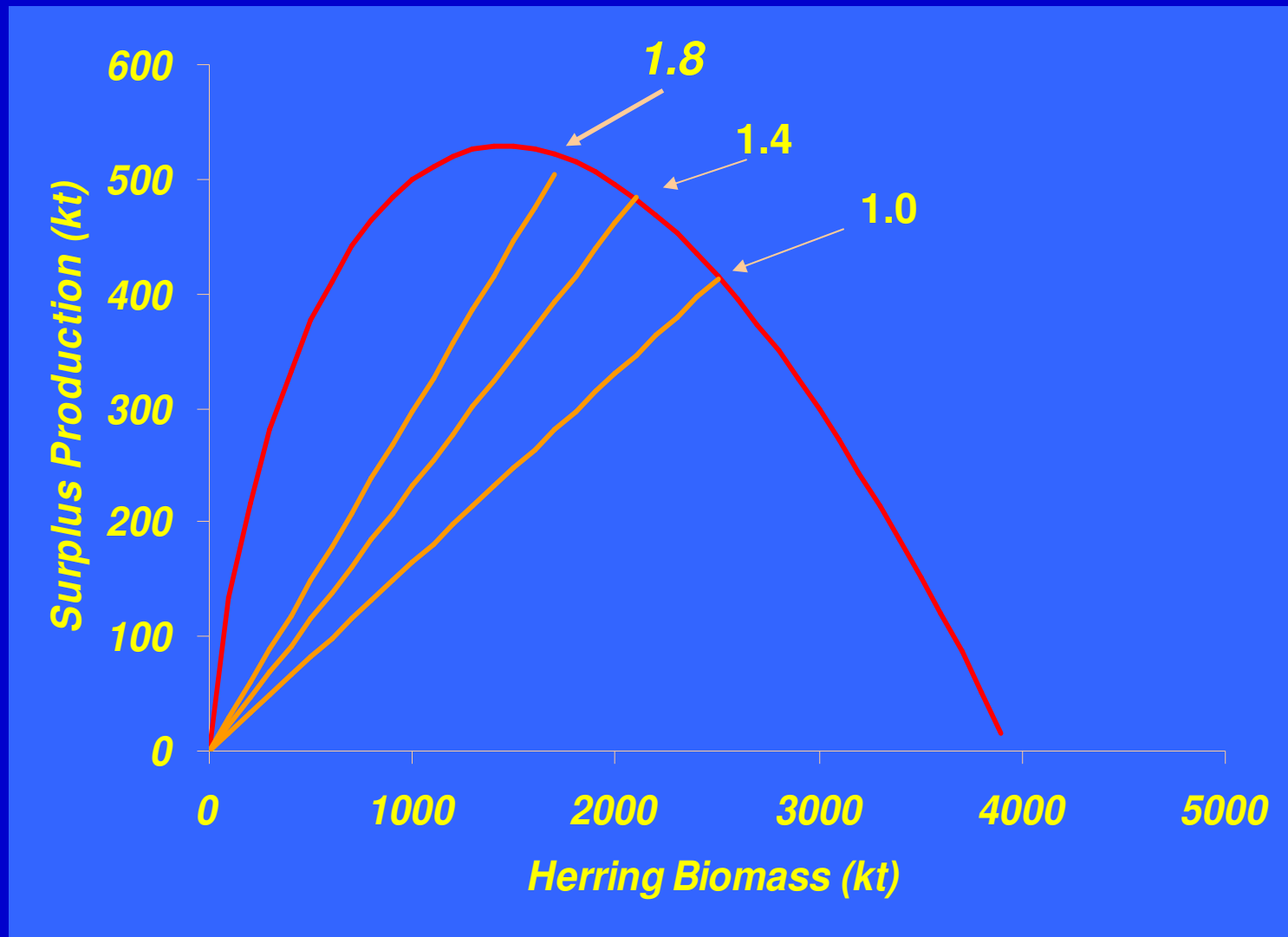
$$PD = (MSY_{pf} \times M2) / f_{MSY_{pf}}$$

An Analytical approach was used to calculate Y for several levels of Predator biomass and herring Biomass. Uses the Fox model with an additional term for predation intensity. Non-equilibrium estimation, it uses a model based on time series approach

Modified Fox model

$$SP_{pf} = -\exp(MSY_{pf}) \frac{B}{k} \ln \frac{B}{k} - PD$$

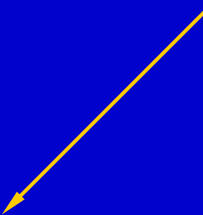
Total SP (curve) and consumption of herring at several values of predator biomass ($p=1.0$, $p=1.4$, $p=1.8$) over a range of herring biomass



(Overholtz et al. 2008 in NAJFM)

<i>predator</i>	<i>SP-predator</i>	<i>SP-fishery</i>
600	144	395
800	192	347
1000	240	299
1200	287	251
1400	335	204
1600	383	156
1800	431	108
2000	479	60

If predators increase, less fishery SP would be available



At Bmsy=1452 kt

- Fishery SP at the recent estimate of Predator Biomass ($P=1.2$ million t) is 232, 000 t.



- If we assume that MM Biomass will continue to increase at roughly 3,000 t/yr and medium fish will rebuild at a rate 5,000-10,000 t/yr.

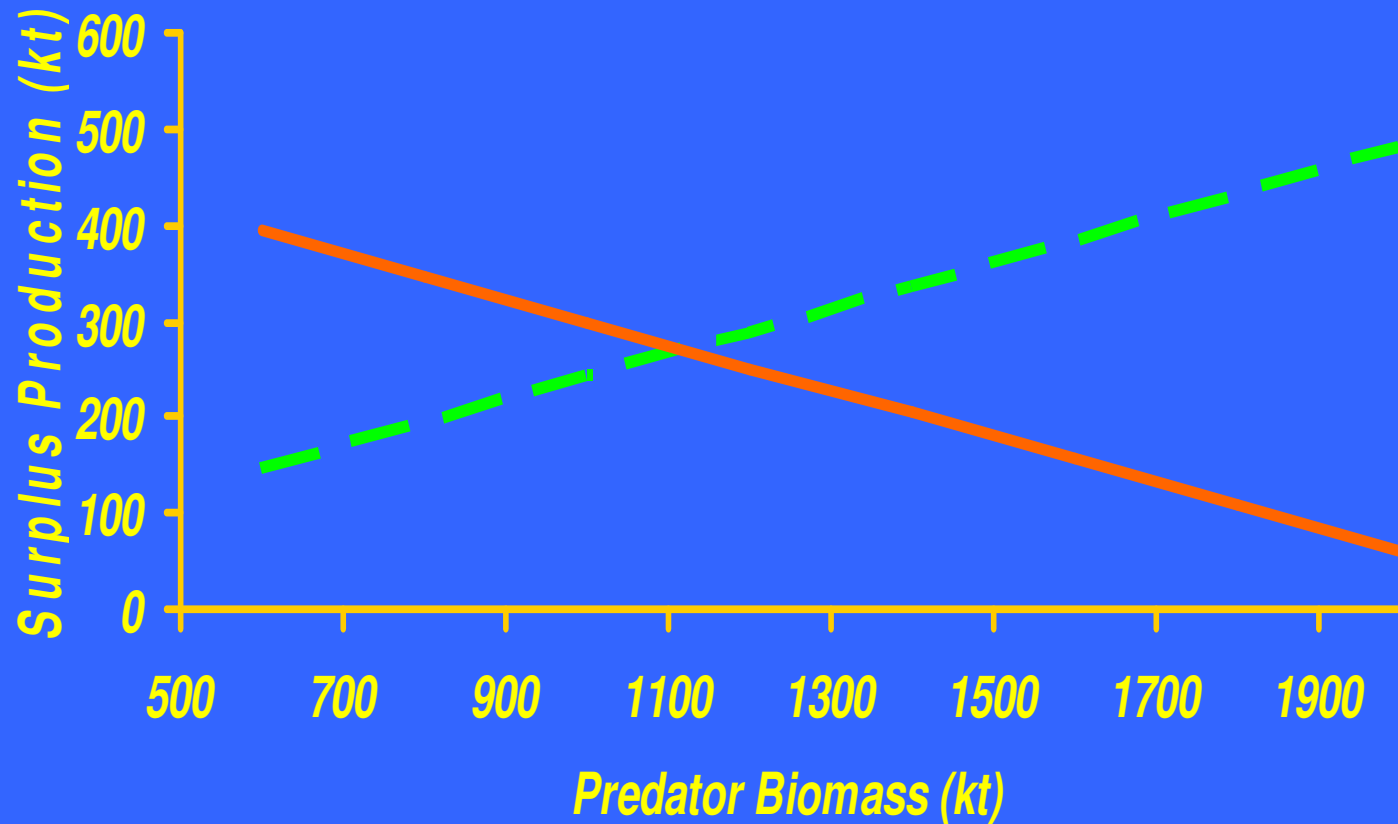


- Then Predator biomass could easily increase to 1.4 million t during the next decades.



- If this occurs the available fishery SP would drop to 179, 000 t.
- Further increase will require further reductions in the surplus yield available to the herring fishery.

Predator vs Fishery Tradeoff



If predators increase, less fishery SP would be available

At Bmsy=1452 kt

— SP-pred — SP-fishery

SP available to predators and herring fishery at BMSY (1452 kt) for Predator B from 0.6-2.0 million t

Conclusions

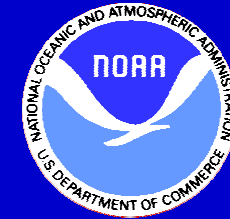
- Predation removals are often equal or larger than landings For Mackerel and Herring
- Predation mortality should be included in analyses of prey fish dynamics if predator biomass changes substantially over time and particularly if there are trends of increasing or decreasing predator biomass.
- Traditional SS assessments (M constant) of Mackerel and Herring can be optimistic relative to BRPs
- If the fishery and predators utilize the same size spectrum of prey, then tradeoffs are probably warranted.

Conclusions continue...

- Documenting the impact of predators on prey is useful information for managers of small pelagic fisheries to allow them to adjust fishery yield estimates based on changes in predator populations.
- As we continue to move towards implementing an Ecosystem Approach to Fisheries (EAF), this SS approach and similar approaches will continue to be valuable to evaluate effect of incorporating ecological interactions.


Acknowledgments

We thank the members of the Food Web Dynamics Program (FWDP) past and present, for collecting and maintaining the database which enabled us to execute this work.



This work was supported by Lenfest Ocean Program



An underwater scene featuring a large shark in the center, its mouth wide open, surrounded by a dense school of smaller fish. A blue thought bubble is positioned to the right of the shark's head, containing the text "Thank you for taking in consideration my Quotas".

*Thank you for taking
in consideration
my Quotas*