Tuna Trends

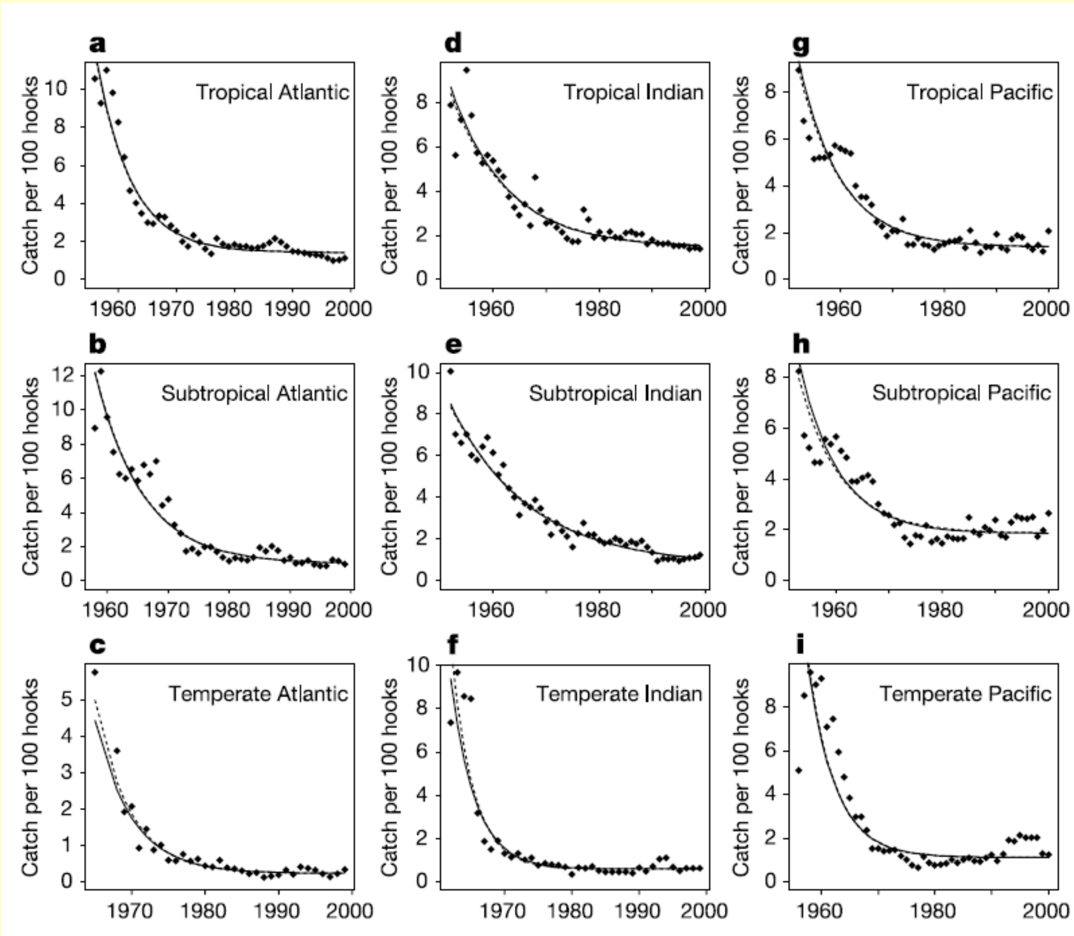
Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)

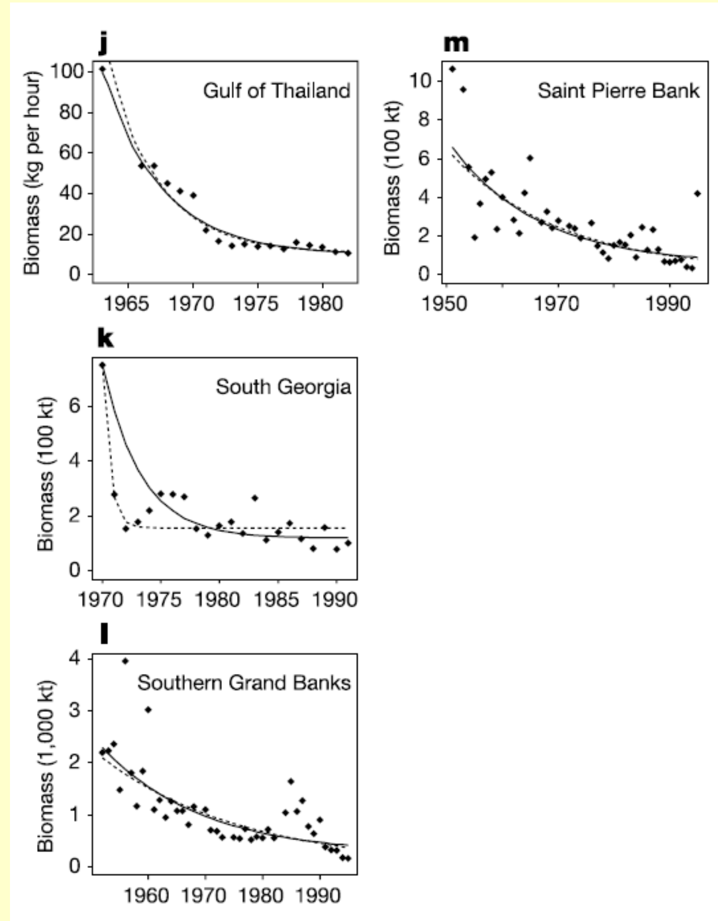
Approach:

Constructed trajectories of community biomass and composition of large predatory fishes in four continental shelf and nine oceanic systems, using all available data from the beginning of exploitation.

Used meta-analysis (many species included in same time-series analysis) approach to estimate large predatory fish biomass in today's ocean – with respect to historical levels.

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)





Oceanic Fisheries – Pelagic Longlines

(catch per # hooks)

Shelf Fisheries – Trawling

(biomass tons, kg per hour)

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)

Results:

Industrialized fisheries reduced community biomass by 80% within 15 years of exploitation.

Compensatory increases in fast-growing species were observed, but often reversed within a decade.

Estimate that large predatory fish biomass today is only about 10% of pre-industrial levels.

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)

For each shelf and oceanic community, i, we estimated

$$N_i(t) = N_i(0)[(1-\delta_i)e^{-r_i t} + \delta_i]$$

where $N_i(t)$ is the biomass at time t, $N_i(0)$ is the initial biomass before industrialized exploitation, and r_i is the initial rate of decline to δ_i, the fraction of the community that remains at equilibrium.

- Time Keeping (discrete / continuous / instantaneous) ?
- Stochastic OR Deterministic ?

The initial rate of decline in total biomass—that is, the fraction lost in the first year—is $(1-\delta_i)(1-e^{-r_i})$. Then we combined all data using nonlinear mixed-effects models[13], where $r_i \sim N(\mu_r, \sigma_r^2)$ and $\log\delta_i \sim N(\mu_\delta, \sigma_\delta^2)$, to estimate a global mean and variance of r_i and δ_i.

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)

How can we compare all these different time series ?
(some species are very numerous / other are rare…)

$$N_i(t) = N_i(0)[(1 - \delta_i)e^{-r_i t} + \delta_i]$$

All of these calculations are based on proportions
(% of the starting biomass – “virgin biomass”):

- Sigma: is a proportion
- r: is the proportional rate of change

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)

Region	r_i (× 100)		
	Individual fit	CL	Mixed model
Tropical Atlantic	16.6	13.5–19.7	16.7
Subtropical Atlantic	12.9	10.1–15.7	13.0
Temperate Atlantic	21.4	15.8–26.9	20.3
Tropical Indian	9.2	7.1–11.4	9.5
Subtropical Indian	6.5	5.1–7.8	6.8
Temperature Indian	30.7	23.7–37.8	27.7
Tropical Pacific	12.1	9.4–14.8	12.4
Subtropical Pacific	12.8	8.5–17.1	13.5
Temperate Pacific	20.8	14.3–27.3	20.4
Gulf of Thailand	25.6	18.2–33.0	22.2
South Georgia	166.6	2.2–331.1	30.8
Southern Grand Banks	4.0	2.9–5.1	5.7
Saint Pierre Banks	5.1	0.1–10.1	6.3
Mixed model mean			16.0
Mixed model CL			10.7–21.3
Distribution			4.5–31.6

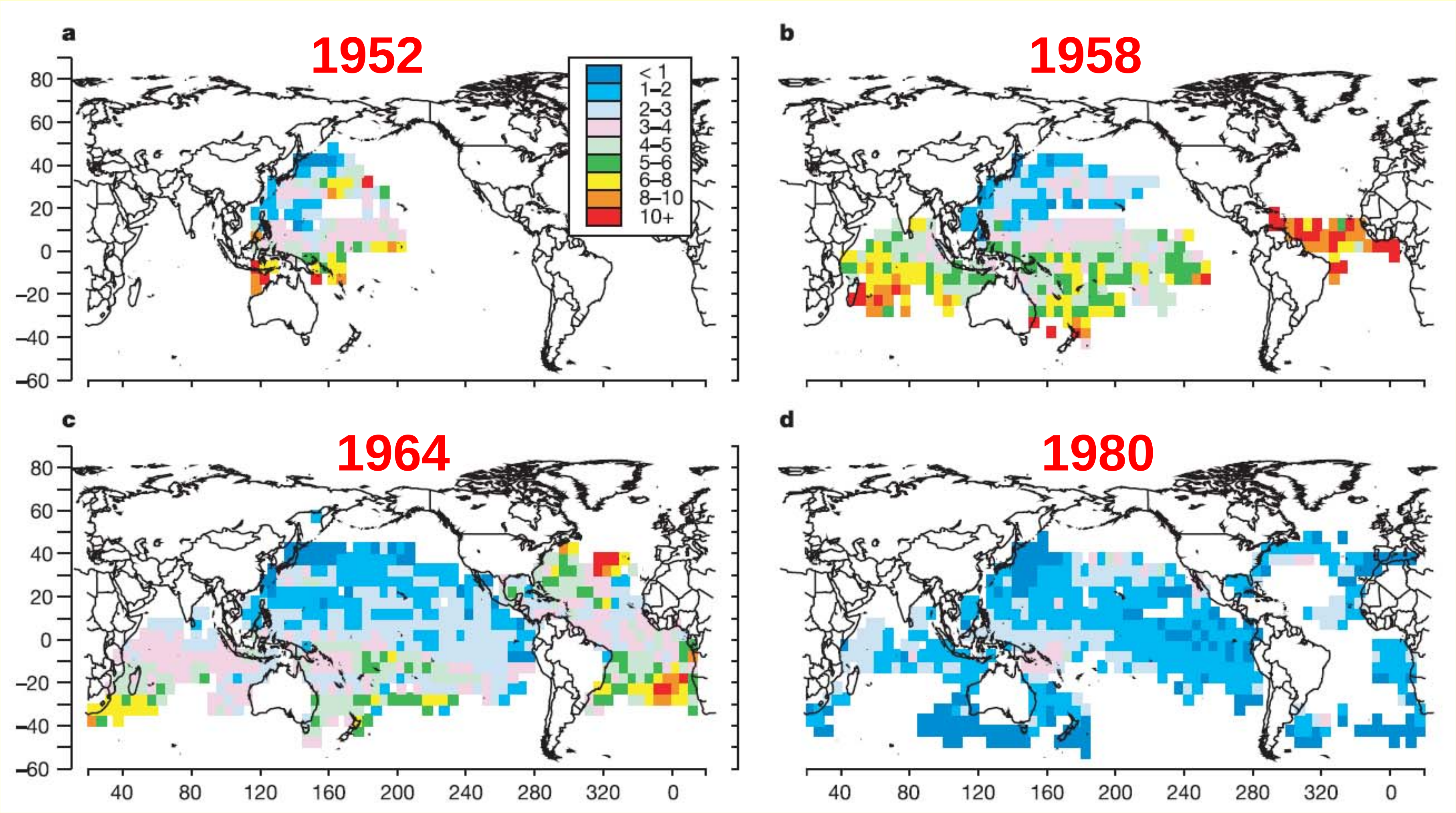
Rapid rate of decline (4 – 31% per year)

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)

Region	δ_i (× 100) Individual fit	CL	Mixed model
Tropical Atlantic	12.1	10.0–14.5	11.9
Subtropical Atlantic	8.1	6.4–10.2	8.3
Temperate Atlantic	4.7	3.2–6.9	5.3
Tropical Indian	17.6	14.9–20.6	16.8
Subtropical Indian	8.2	5.5–12.3	9.2
Temperature Indian	5.5	3.9–7.7	6.3
Tropical Pacific	15.5	13.0–18.6	14.9
Subtropical Pacific	23.5	18.9–29.3	21.5
Temperate Pacific	8.2	5.6–12.1	8.5
Gulf of Thailand	9.3	6.8–12.6	9.8
South Georgia	20.9	17.5–25.0	16.0
Southern Grand Banks	0.0	–	10.0
Saint Pierre Banks	2.7	0.0–36600	7.9
Mixed model mean			10.3
Mixed model CL			7.7–13.9
Distribution			4.6–23.6

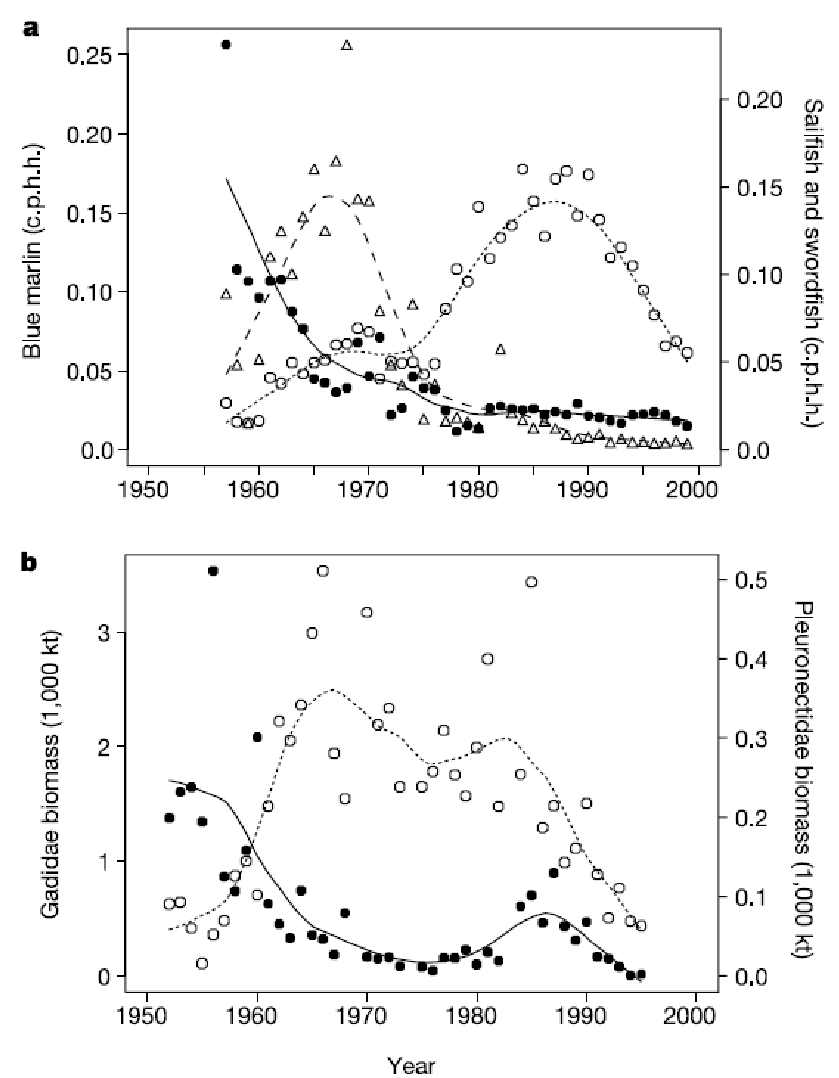
Small equilibrium population (0 – 24 %)

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)



(fish caught per 100 hooks on pelagic longlines set by the Japanese fleet)

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)



Compensation in exploited fish communities.

a, Oceanic billfish community in the tropical Atlantic, showing the catch per 100 hooks (c.p.h.h.) of blue marlin (solid circles, solid line), sailfish (open triangles, dashed line) and swordfish (open circles, dotted line).

b, Demersal fish community on the Southern Grand Banks, showing the biomass of codfishes (solid circles, solid line) and flatfishes (open circles, dotted line).

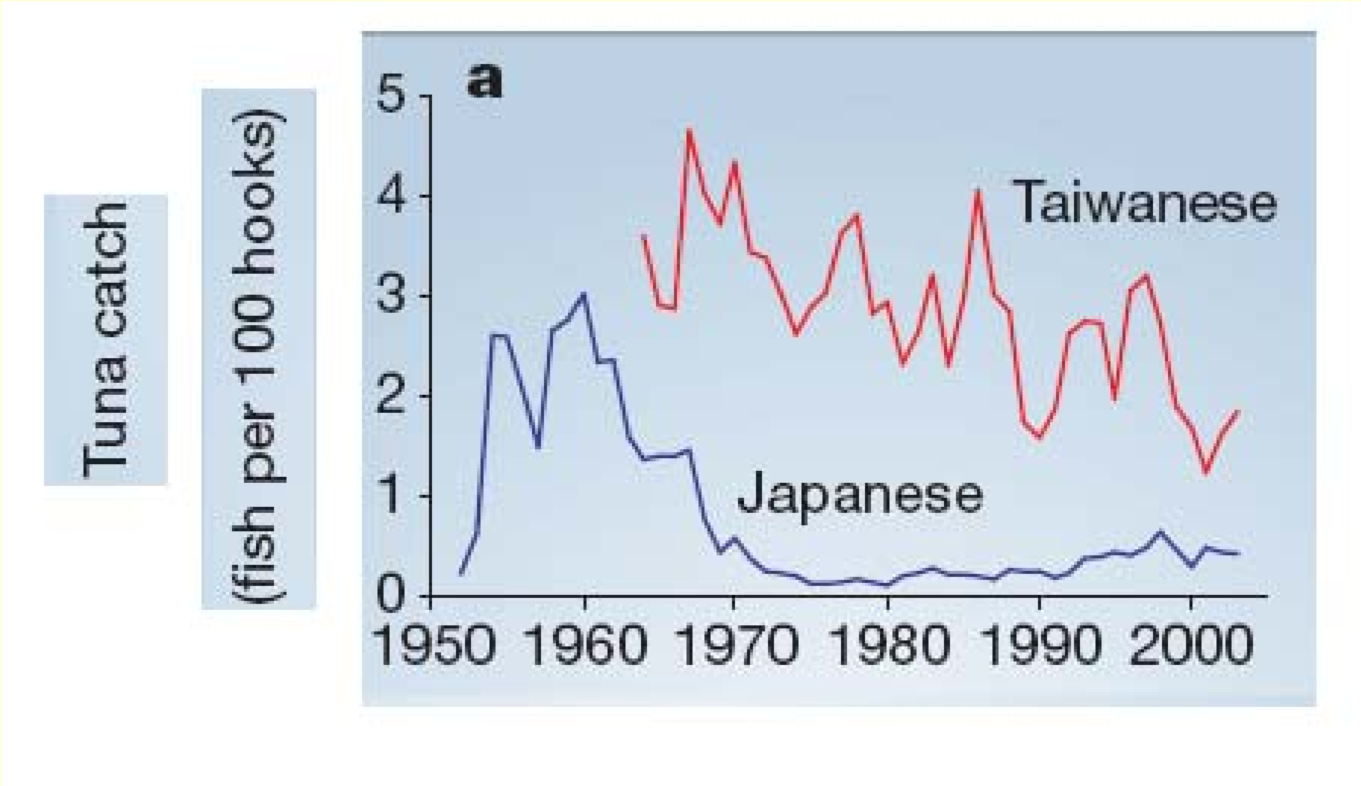
Response to Myers and Worm (2003) (Hampton et al. 2005)

We show here that an assumption critical to this conclusion
- namely, that Japanese longline CPUE acts as an accurate index of community biomass - is invalid.

Our results indicate that biomass decline and fishing impacts are much less severe than is claimed by Myers and Worm.

Response to Myers and Worm (2003) (Hampton et al. 2005)

1) Line of Evidence #1:



Albacore tuna CPUE by Taiwanese (red) and Japanese (blue) longliners in the Pacific Ocean, south of the Equator.

Rapid worldwide depletion of predatory fish communities (Myers & Worm 2003)

CPUE   f (N, E, q)

Response to Myers and Worm (2003) (Hampton et al. 2005)

Interpretation of the species-aggregated CPUE as an index of community biomass rests on the assumption that catchability is constant across species and over time.

What is Catchability?

Coefficient specifying proportionality between CPUE and abundance

What influences Catchability?

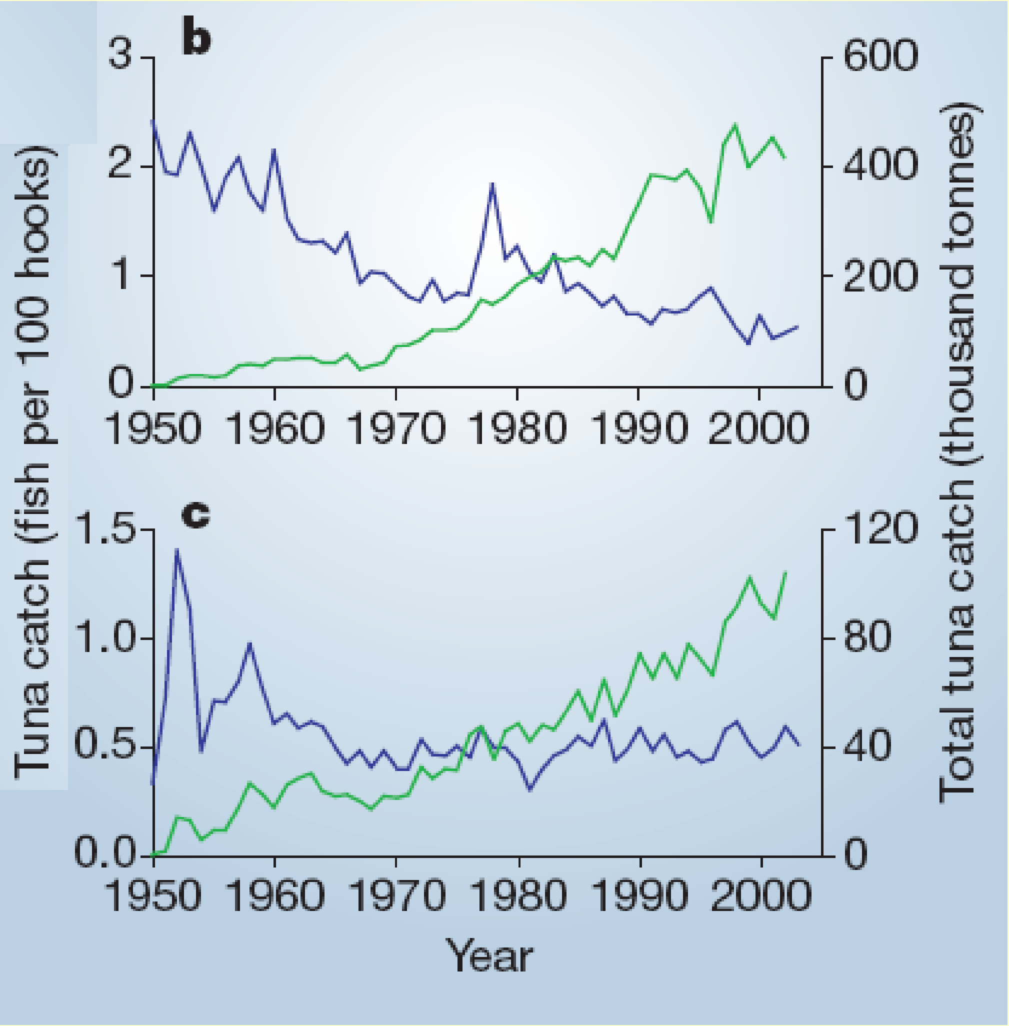
The fishery (gear/practices), the fish (length/mouth), the ocean (depth)

Response to Myers and Worm (2003) (Hampton et al. 2005)

2) Line of Evidence #2:

b, Yellowfin tuna CPUE by Japanese longliners (blue) and catch by all fleets (green) in western Pacific Ocean (west of 150° W, south of 20° N).

c, Bigeye tuna CPUE by Japanese longliners (blue) and catch by all fleets (green) in western Pacific Ocean (west of 150° W, south of 20° N).



Questions

Ecosystem Conservation: "United Nations resolution on restoring fisheries and marine ecosystems to healthy levels"

Status of Exploitation: Appraisal of exploitation describes the effect of current fishing effort on each stock, and is based on current data and the knowledge of the stocks over time.

Levels categorized using the terms:

unknown, protected, not exploited, underexploited, moderately exploited, fully exploited, and over-exploited.

Questions

Levels defined by relation of B / B_{MSY}

- *underexploited > 1.5*
- *moderately exploited: 1.5*
- *fully exploited: 1*
- *over-exploited < 1*

Questions

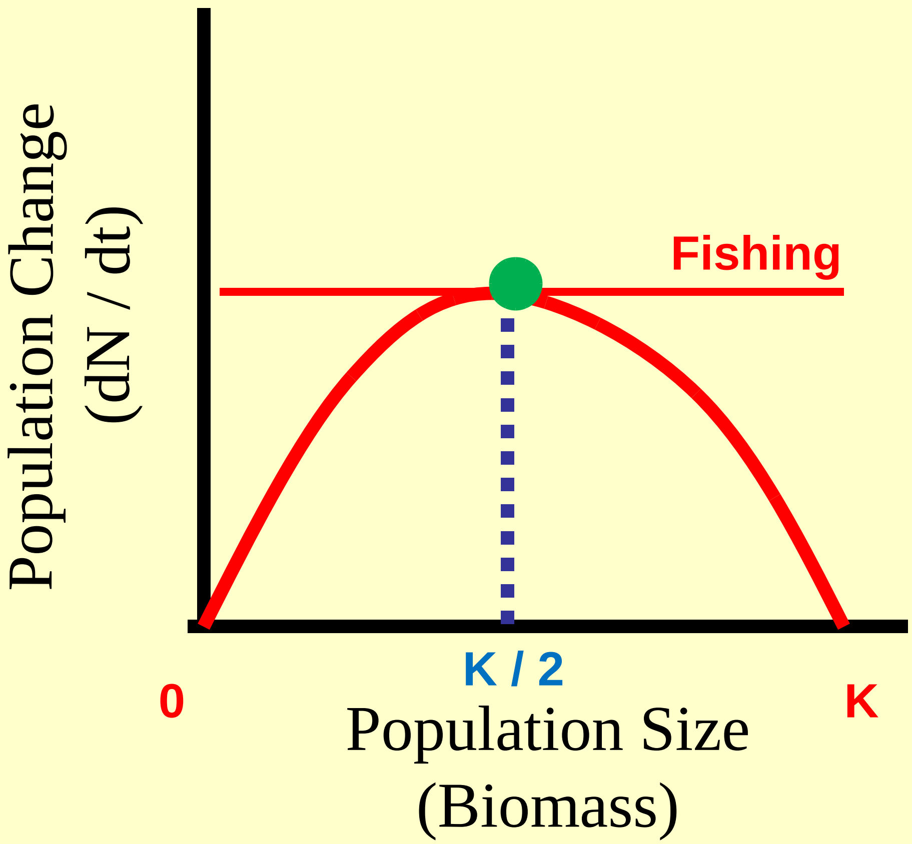
What is MSY: Maximum Sustainable Yield

Theoretically, the largest yield (or catch) that can be taken from a stock over an indefinite period (for ever).

MSY aims to maintain the population size at the point of maximum growth rate by harvesting the “excess” individuals that would normally be added to the population, allowing the population to continue to be most productive indefinitely.

Questions

Assumptions: Carrying Capacity (Logistic Growth)



dN / dt = r N (N – K)

dN / dt = (r N N) – (r N K)

Take derivative w.r.t. N

dN / dt dN = (2 r N) – (r K)

Two solutions:

1)Trivial: r = 0

2) 2N = K

Extinction and Recovery

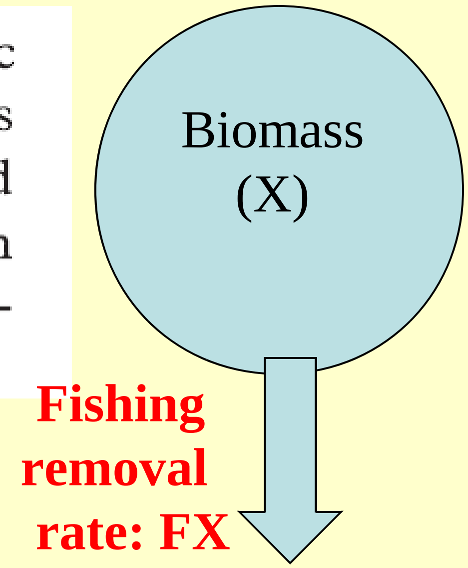
(Myers and Worm 2005)

The simplest assumption for this case is

$$\frac{dx}{dt} = r_{max}x(1 - g(x)) - Fx,$$

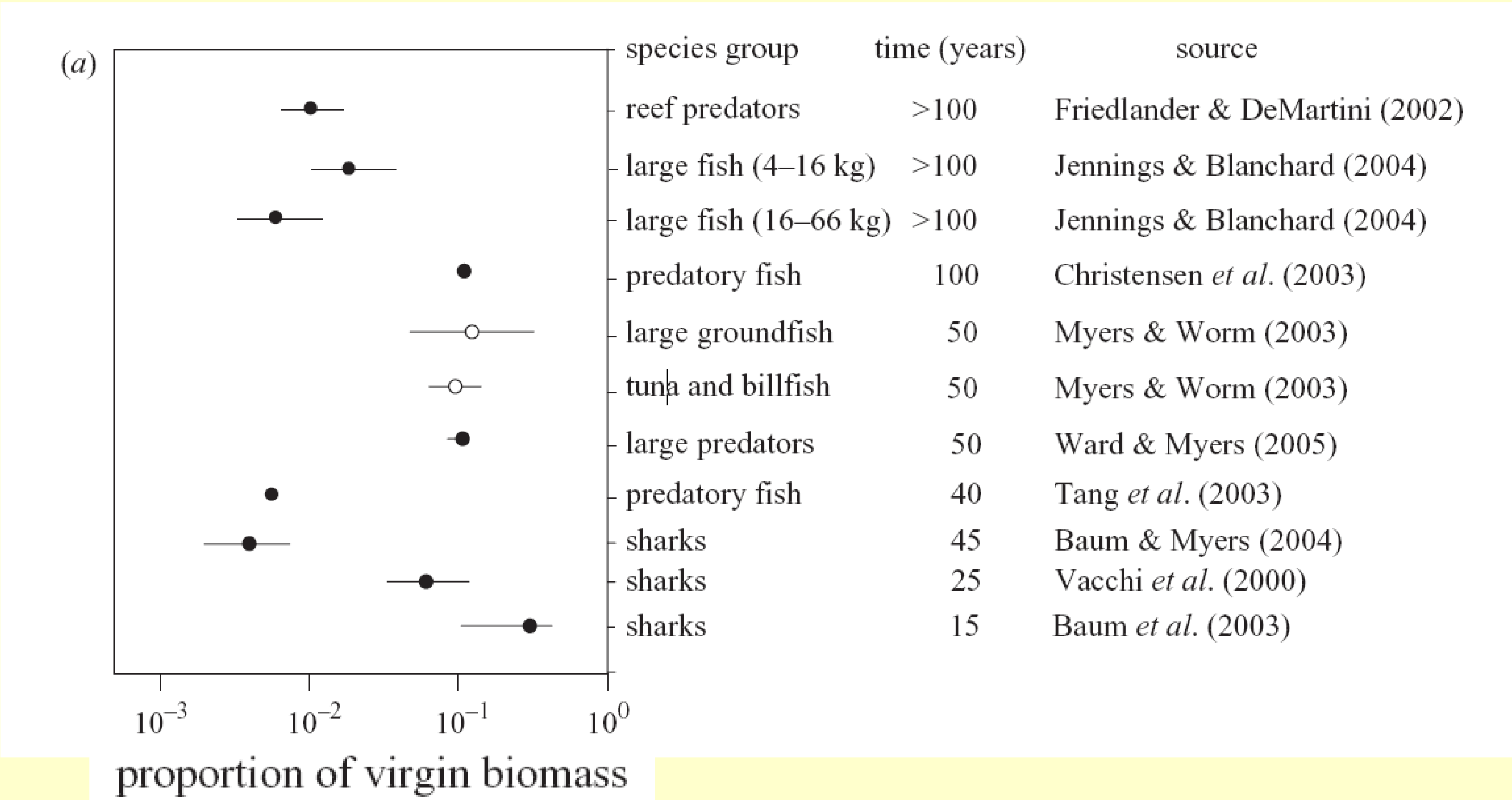
dN / dt = r * N * (1 – N/K)

where $g(x)$ is the density-dependent term (for logistic population growth $g(x) = x/K$) and F is the instantaneous fishing mortality (Clark 1990). If the population is reduced to low population size, which is a reasonable assumption for many exploited shark populations, then density dependence will be small, and we can assume that $g(x) \approx 0$.



Extinction and Recovery

(Myers and Worm 2005)



Extinction and Recovery

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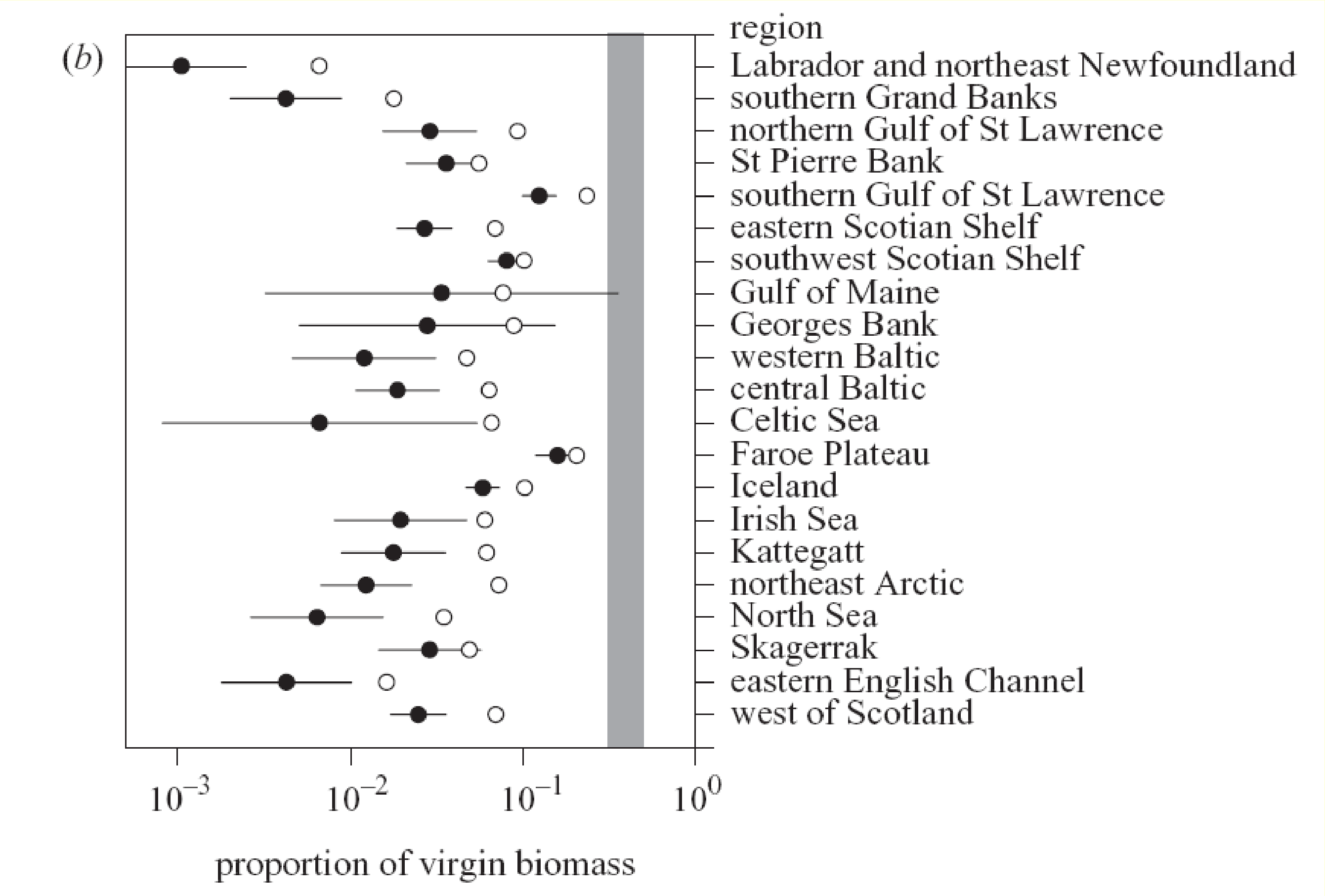
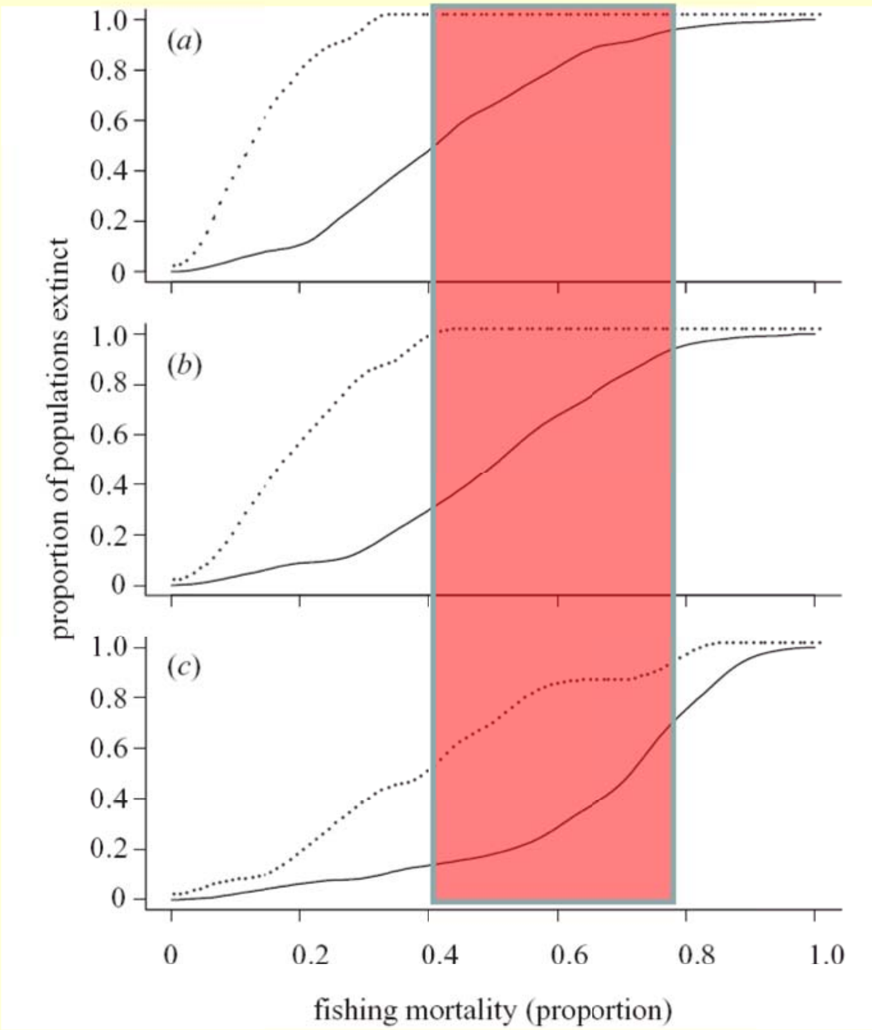


Shaded bar refers to the proportional biomass commonly assumed to allow for maximum sustainable yield

(0.3< B_{MSY} <0.5)

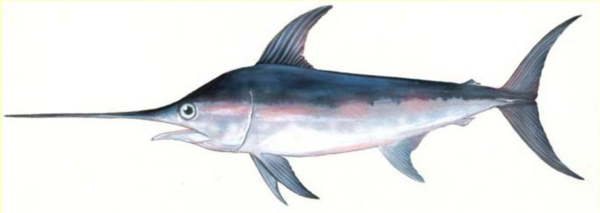
Extinction and Recovery

(Myers and Worm 2005)

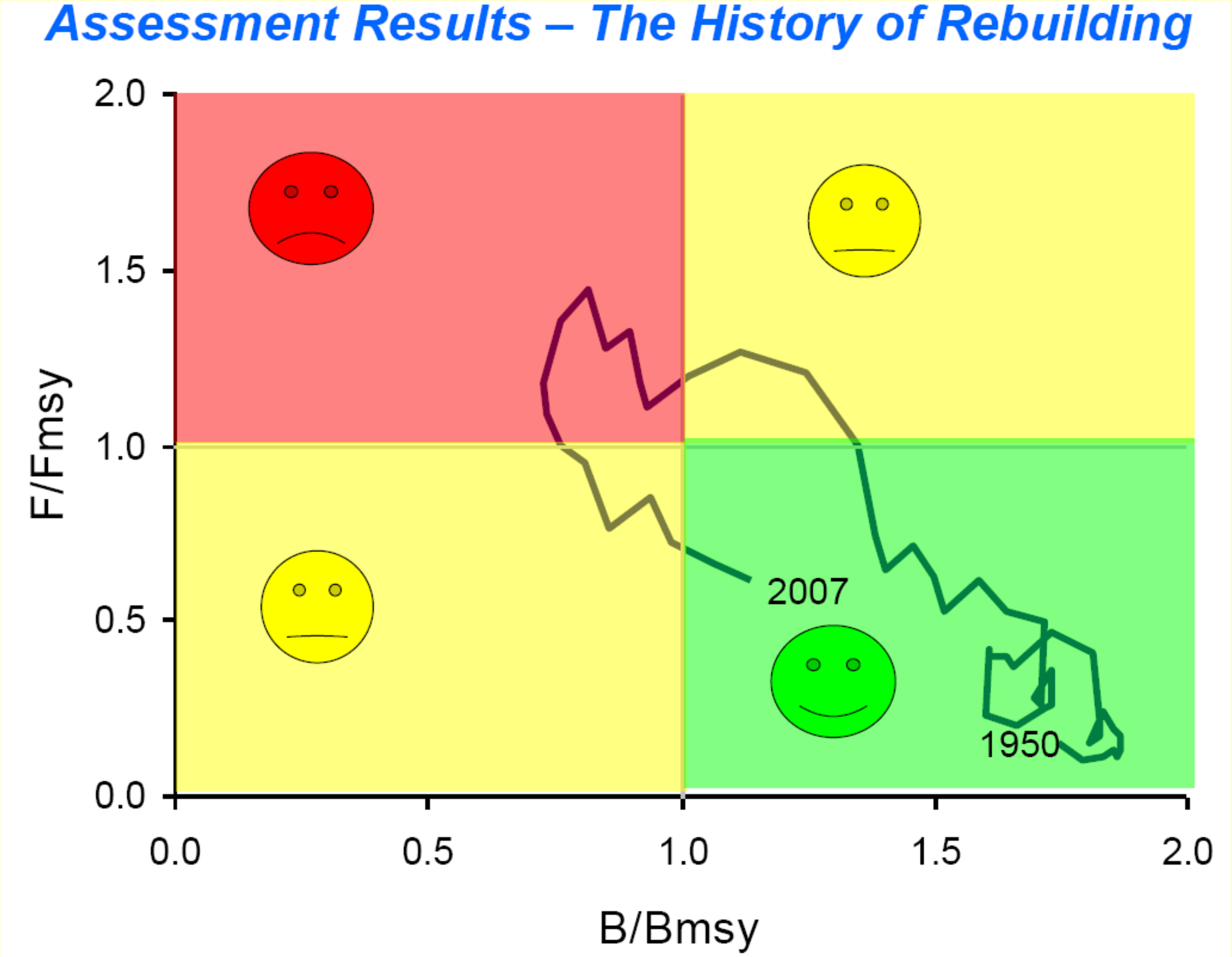


Fishing mortality required to drive populations of sharks (dotted line) and bony fishes (solid line) to extinction under three scenarios:
(a) fishing mortality constant at age of recruitment,
(b) fishing mortality constant at midpoint between age at recruitment and age at maturity,
(c) fishing mortality constant at age of first maturity.

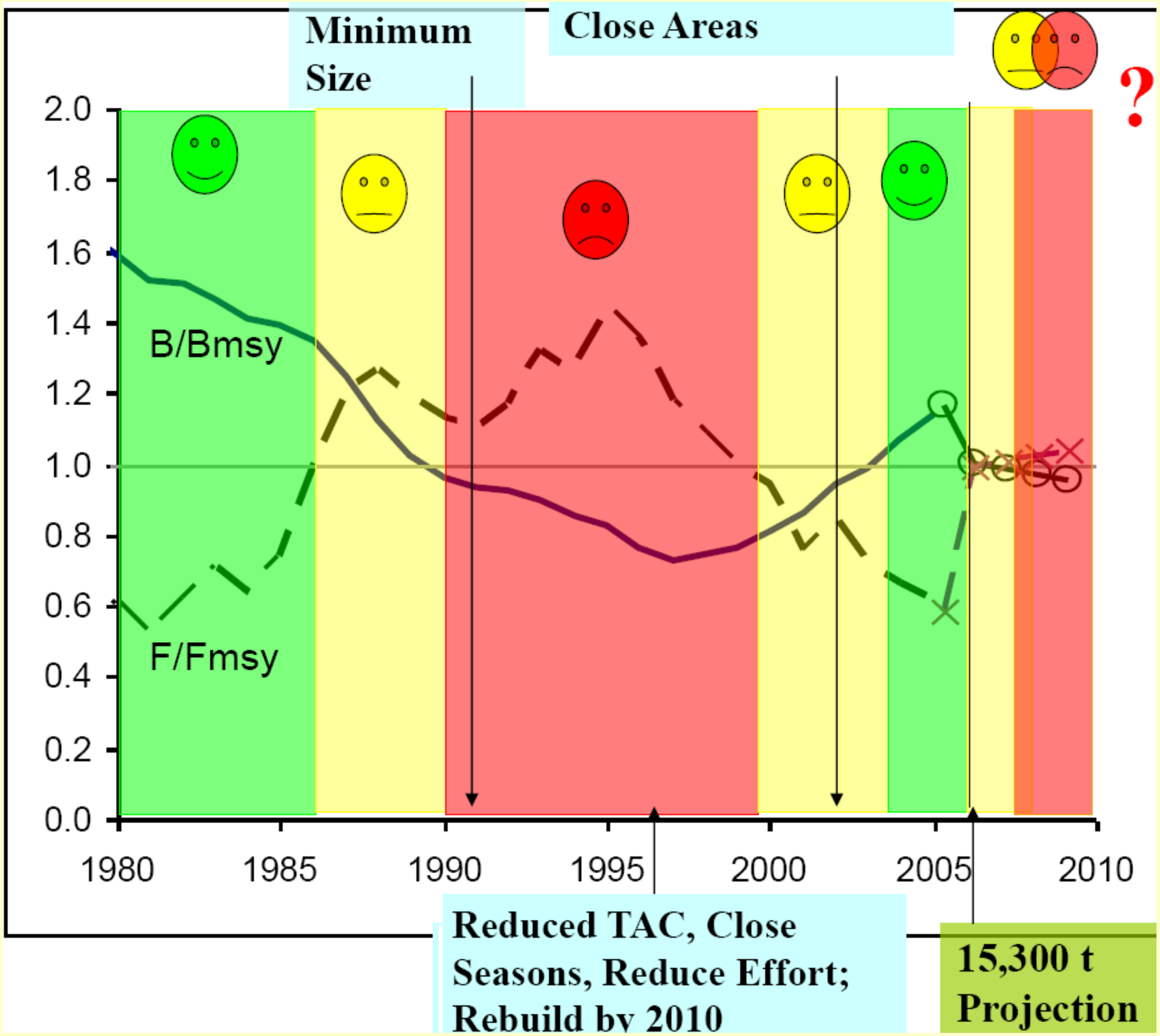
Example – Atlantic Ocean Swordfish



Stock status based on Biomass and Fishing level, with respect to the MSY levels



Example – Atlantic Ocean Swordfish



Fisheries Management with Safeguards

- Decrease fishing mortality below MSY levels: $F / F_{MSY} = 0.75$

- Increase biomass above MSY levels: $B / B_{MSY} > 1.00$

According to Myers and Worm (2005):

- Decrease fishing mortality (F)

- Delay onset of this mortality (after maturity)

Example – Atlantic Ocean Swordfish

The Report Card for ICCAT Stocks

ICCAT Stock Status Report Card, 2008					
Stock	F/FMSY	B/BMSY	Last/Next Assessment	Most Likely	Possibly
BFT-E	>3	~.2	2008/2010		
BFT-W	1.3-2.2	.14-.6	2008/2010		
BUM	>1	<<1	2006/2010		
ALB-N	1.5 (1.3-1.7)	0.8 (0.68-0.97)	2007/2011		
SWO-M	1.3-2.9	0.3-0.9	2007/?		
WHM	Possibly ~>1	<<1	2006/2010		
SMA	Possibly ~>1	Likely<1	2004/2008		
YFT	0.85 (0.7-1.1)	0.95 (0.7-1.18)	2008/?		
BET	0.9 (0.7-1.2)	0.9 (0.85-1.07)	2007/2011		
SWO-N	0.9 (0.65-1.04)	0.97 (0.87-1.27)	2006/2009		
ALB-S	0.6 (0.47-0.9)	0.9 (0.71-1.16)	2007/2011		
SWO-S	Likely <1	Likely >1	2006/2009		
BSH	Likely<1	Likely>1	2004/2008		
SKJ-W	>1	<1	2008/?		
SKJ-E	>1	<1	2008/?		

Chaos From Deterministic Models

Chaos theory is a field of mathematics, studying the behavior of dynamic systems that are highly sensitive to initial conditions (the “butterfly effect”).

Small differences in initial conditions (such as those due to sampling and rounding errors) yield widely diverging outcomes for chaotic systems, rendering long-term prediction impossible.

This occurs even though these systems are deterministic, meaning that their future dynamics are fully determined by their initial conditions, with no random elements (noise) involved.

In other words, the deterministic nature of these systems does not make them predictable. This behavior is known as deterministic chaos, and occurs in many natural systems.

Homework #3

Nature **261** 459–67 (1976)

Simple mathematical models with very complicated dynamics

Robert M. May*

First-order difference equations arise in many contexts in the biological, economic and social sciences. Such equations, even though simple and deterministic, can exhibit a surprising array of dynamical behaviour, from stable points, to a bifurcating hierarchy of stable cycles, to apparently random fluctuations. There are consequently many fascinating problems, some concerned with delicate mathematical aspects of the fine structure of the trajectories, and some concerned with the practical implications and applications. This is an interpretive review of them.

$$N_{t+1} = a * N_t * (1 - N_t)$$

$$N_{t+1} = N_t * [1 + R (1 - (N_t / K))]$$

Homework #3

$$N_{t+1} = N_t * [1 + R (1 - (N_t / K))]$$

As population growth rate (Lambda = R + 1) increases… something magical happens.

The deterministic model gives raise to unpredictable behaviors…