A Taste of Fisheries Science: Reference Points

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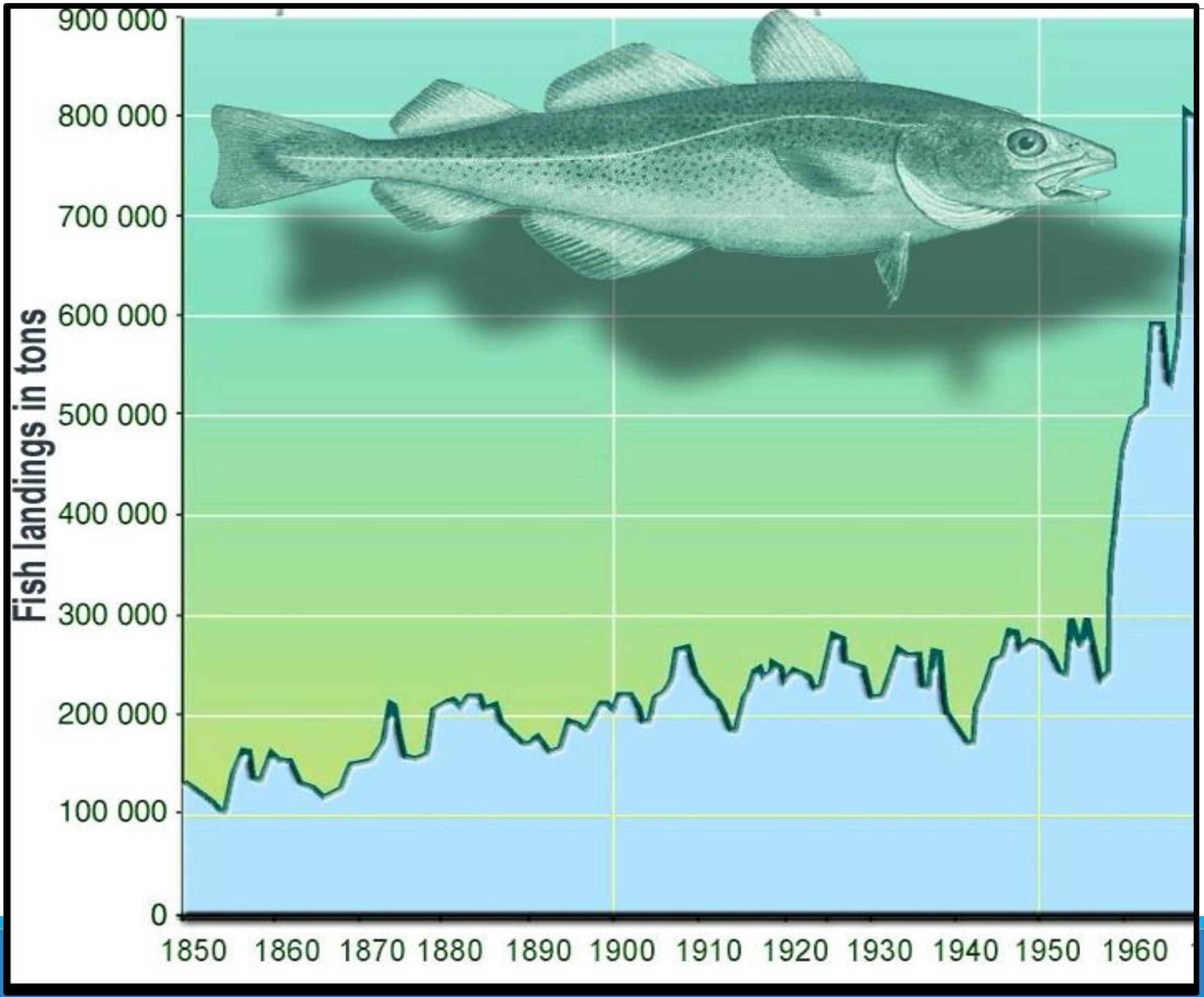
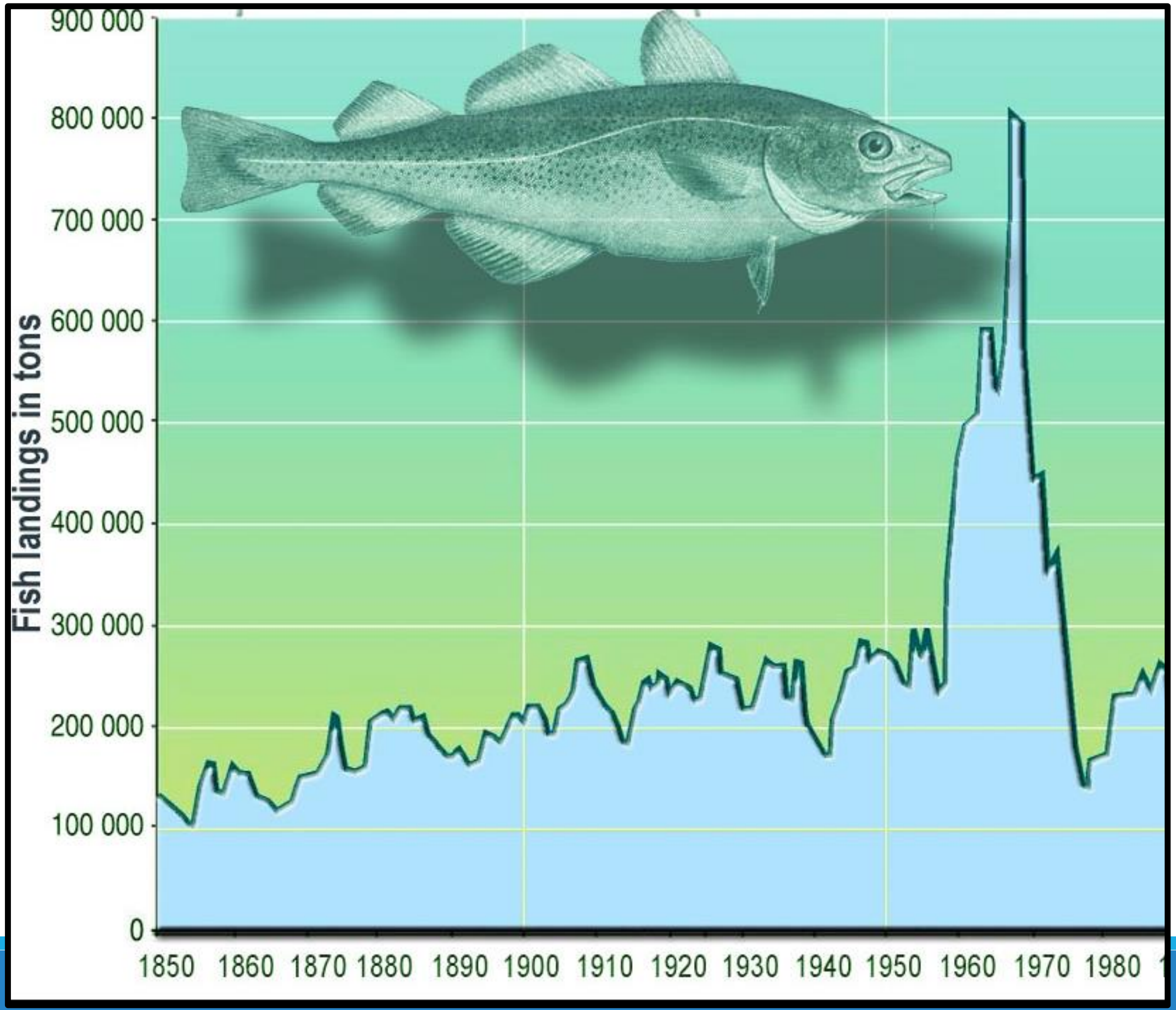
FISHERIES AND OCEANS, CANADA

Do Catches Tell Us About a Population?



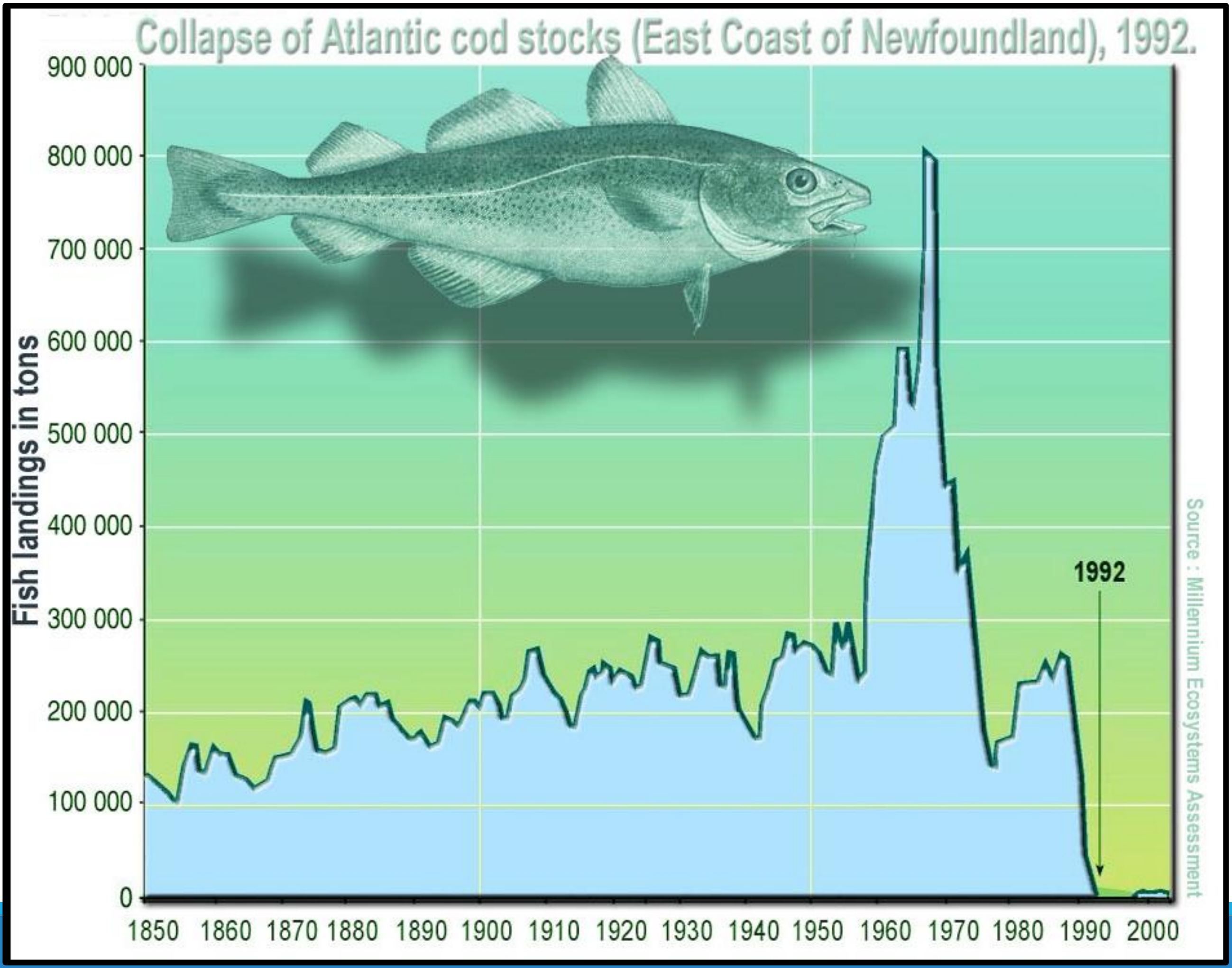
- Catch is proportional to abundance under Baranov's catch equation
- Factors affecting the amount of fish caught
  - Number of vessels
  - Characteristics of vessels
  - Spatial distribution of fishery relative to stock
  - Selectivity and Gear
  - Abundance

What is Management Supposed to Do?



- When catches are declining, management is supposed to be more restrictive
  - Changes implemented in 1976
- Intention of management is to promote population increase
  - Catches started climbing
  - Levels similar to ~1950s
  - Success??

Everyone Knows How This Story Ends



Obvious that landings do not tell the correct story about the state of the stock

- 1949 Newfoundland joined Canada
- 1960s Factory trawlers entered fishery
- 1969 Canada claimed 200 nm EEZ under UNCLOS
- 1976 Canada declared right to manage within 200 mn EEZ
- 1986 Stock assessment: recommended TAC be cut in half
  - limited knowledge of cod biology
  - no change in management

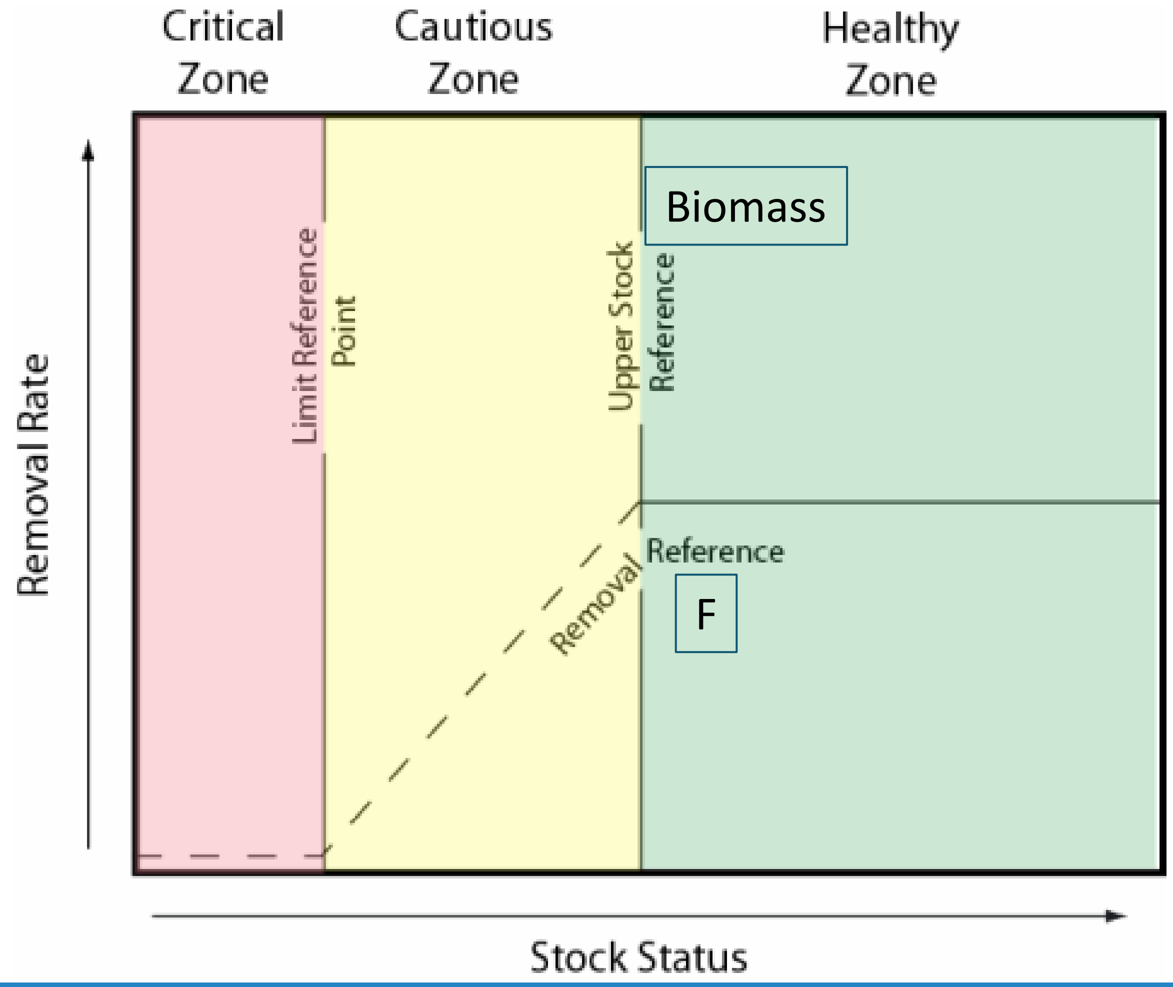
Hindsight Truly is 20:20

- Managers can only use the information that they have available
- Cod example:
  - Canadian research survey was in its infancy (short timeseries)
  - Limited biological knowledge (lifespan, population structure)
  - Scientific basis for decision-making was overly optimistic (retrospective patterns)

  - Foreign vessels left Canadian waters resulting in an apparent increase CPUE;
  - Historical inertia and socioeconomic considerations
  - Unwillingness to take drastic/unpopular [and unprecedented] steps

Precautionary Approach

Being cautious when scientific knowledge is uncertain, and not using the absence of adequate scientific information as a reason to postpone action or failure to take action to avoid serious harm to fish stocks of their ecosystem.



Key Ideas Under PA Framework

LRP: stock level below which productivity is sufficiently impaired to cause series harm but above the level where the risk of extinction becomes a concern; **Critical** Zone

USR: threshold below which the removal rate is reduced; above is the **Healthy** Zone

Between LRP and USR: **Cautious** Zone

Removal Reference: maximum acceptable removal rate; ratio of all human-induced removals to total exploitable stock size

Management: Cautious Zone = actions taken to promote stock rebuilding. Cannot exceed **RR**

Management: Critical Zone = actions **must** promote stock growth; Removals kept to lowest possible level

Reference Points

AN EXCEPTIONALLY BRIEF INTRODUCTION TO THE MOST UNDER-APPRECIATED COMPONENT OF STOCK ASSESSMENT

Types of Overfishing

Growth Overfishing: too many fish are caught while they are very small and haven't had a chance to reproduce

- Fish are harvested at a size that is smaller than the size that would maximize yield

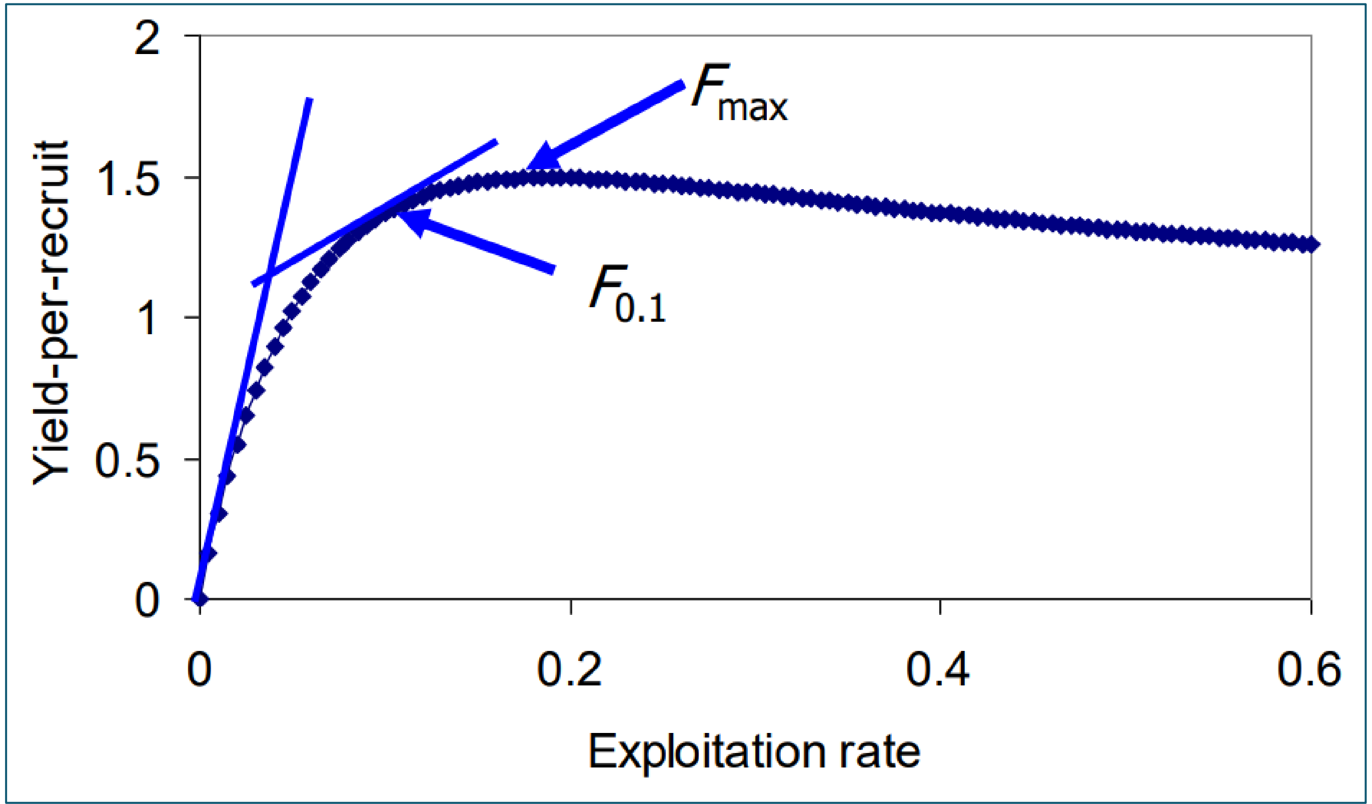
Recruitment Overfishing: exploitation reduces spawning biomass to the point where recruitment is significantly impaired.

- The population is too small to maintain high reproductive rates.

- Both types of overfishing pre-suppose that reference points are **biologically-based** (i.e. appropriate for the life history of the animal)

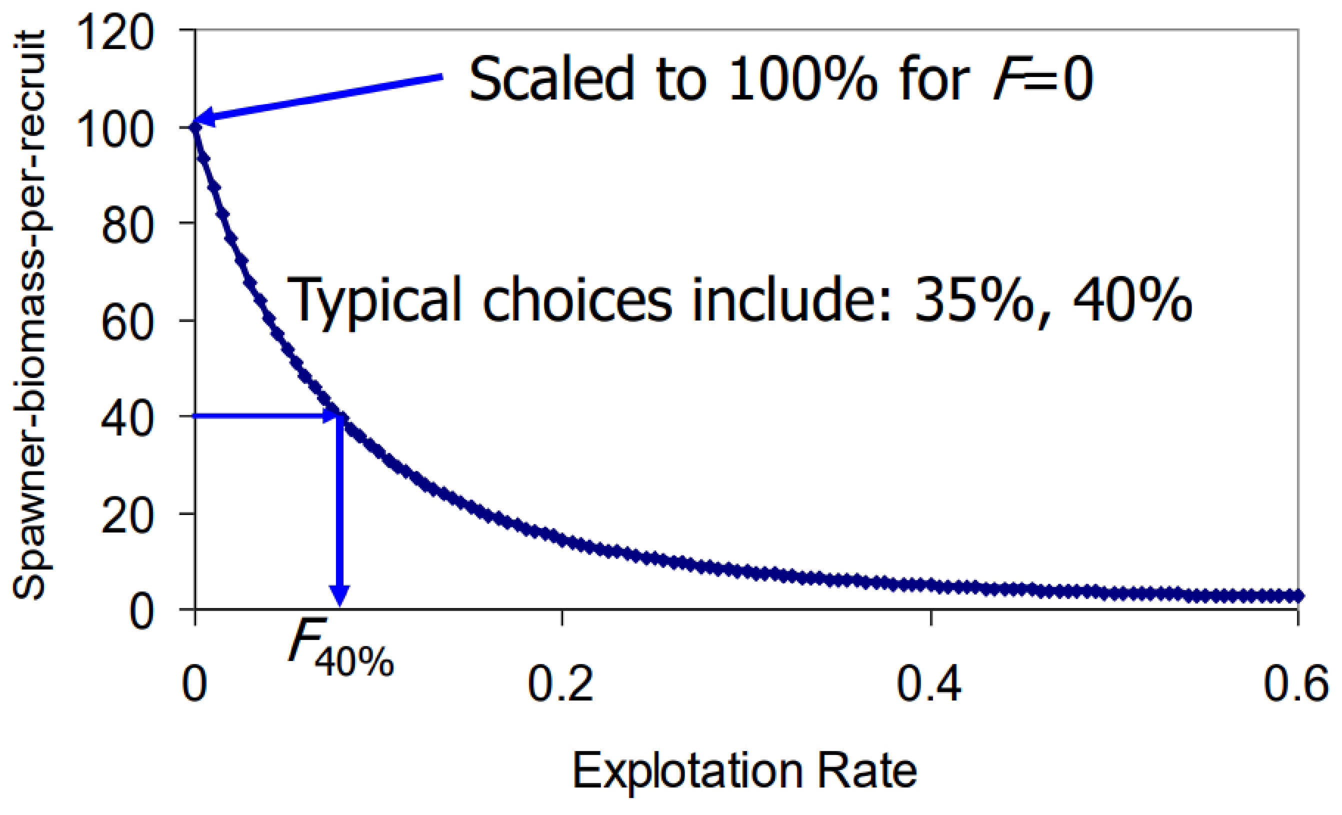
Yield-Per-Recruit (F-based Reference Points)

- Density-independent model where recruitment is assumed constant
- Exploiting the stock at the age/size when the cohort's biomass reaches a maximum
- Depends on:
  - Natural mortality
  - Growth rate
  - Age at first capture or selectivity



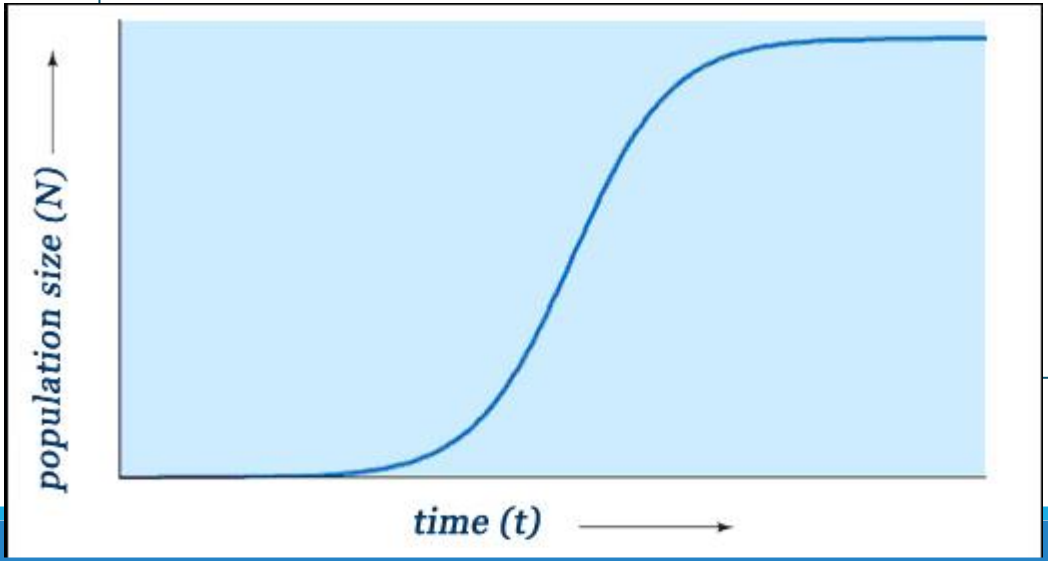
Spawner-Biomass-Per-Recruit (% SPR Reference Points)

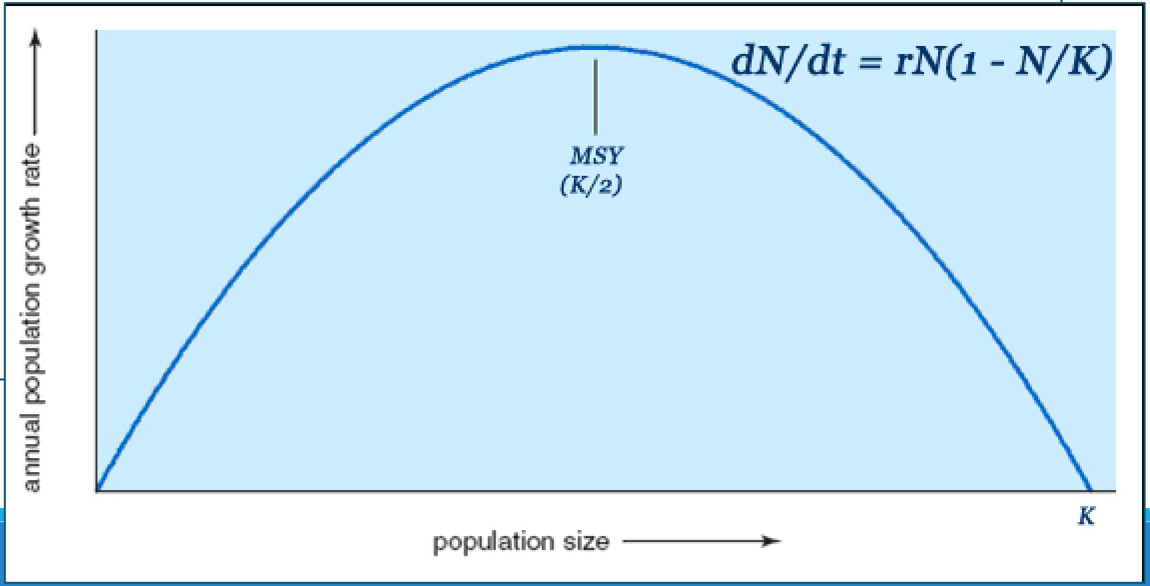
- Fishing mortality rate that reduces unfished spawner biomass per recruit to a given percentage
- Exploiting the stock at a specific percentage of recruits that survive to spawn.
- Depends on:
  - Gear selectivity
  - Growth
  - Fecunity at age
  - Natural mortality



Maximum Sustainable Yield (Fmsy and Bmsy Reference Points)

- The maximum level at which a natural resource can be routinely exploited without long-term depletion
- The size of a natural population at which it produces a **maximum rate of increase**, typically at half of **carrying capacity**





Setting Harvest Levels at MSY

- Consider a population with no age structure

$$\frac{dN}{dT} = rN\left(1 - \frac{N}{K}\right) - H$$

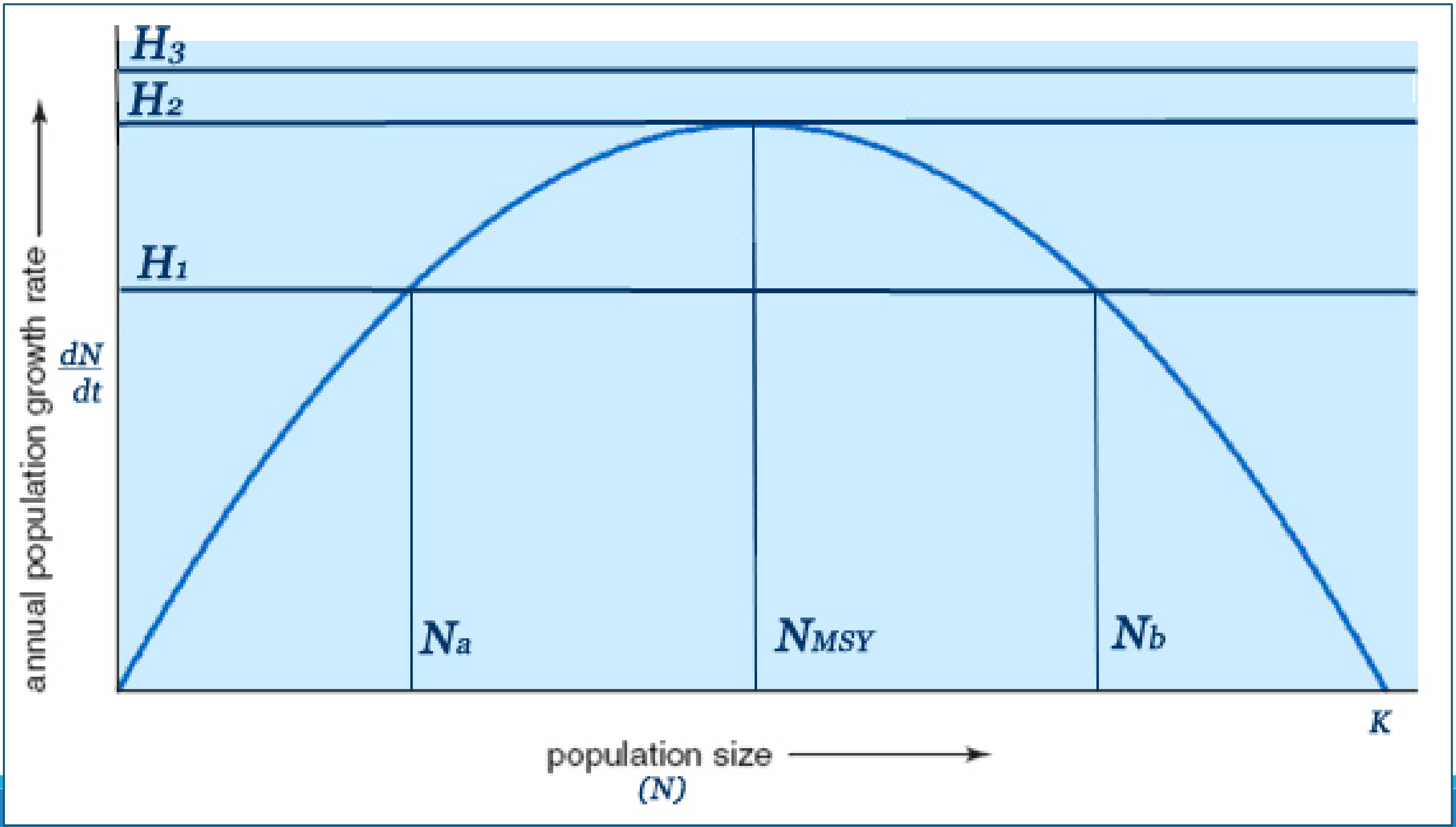
- Equilibrium $$rN\left(1 - \frac{N}{K}\right) = H$$

- Harvesting at H2 = Nmsy; population size that produces the maximum growth rate

$$N = \frac{K}{2}$$

Functional Form depends on Assumed Model for stock assessment

Schaefer



YPR and SPR vs. MSY

- YPR and SPR do not incorporate compensatory dynamics
  - Typically, they do not account for recruitment variability
  - Do not intrinsically protect biomass and reproductive potential
- MSY relies on compensatory dynamics (density dependence)
  - At smaller stock sizes, the rate at which spawners produce recruits will be higher than at large stock sizes
  - Ideally requires the ability to estimate carrying capacity (virgin biomass) and steepness/slope at the origin of an S-R curve

Reference point	Description	
%SPR	spawner per recruit as a percentage of the unfished spawner per recruit - usually set in terms of the harvest rate that implies this	Per recruit
B/B_0	biomass relative to unexploited biomass (or often defined in terms of spawning biomass).	Ad hoc
B_{msy}	the biomass which corresponds with maximum sustainable yield	MSY
MBAL	(Minimum Biological Acceptable Level) a spawning biomass level below which, observed spawning biomasses over a period of years, are considered unsatisfactory and the associated recruitments are smaller than the mean or median recruitment.	Historic estimates of S & R
F_{max}	Fishing mortality rate which corresponds to the maximum yield per recruit (as a function of fishing mortality)	Per recruit
$F_{0.1}$	fishing mortality rate at which the slope of the yield per recruit curve (as a function of fishing mortality) is 10% of its value near the origin. (Similarly defined $F_{0.2}$ has been used in some cases; see Caddy, 1998)	
$F_{spr.x\%}$	fishing mortality rate which corresponds to spawner per recruit being x% of unfished spawner per recruit (values of 30%, 35%, 40% have been used; see e.g. Mace and Sissenwine, 1993)	
F_{low}	fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the 10^{th} percentile of the observed R/SSB	Historic estimates of S & R
F_{med} (F_{rep})	fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the median (50^{th} percentile) of the observed R/SSB	
F_{high}	fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the 90^{th} percentile of the observed R/SSB	
F_{msy}	fishing mortality rate which corresponds to the maximum sustainable yield as estimated by a production model (or age-based model with stock-recruit curve)	MSY

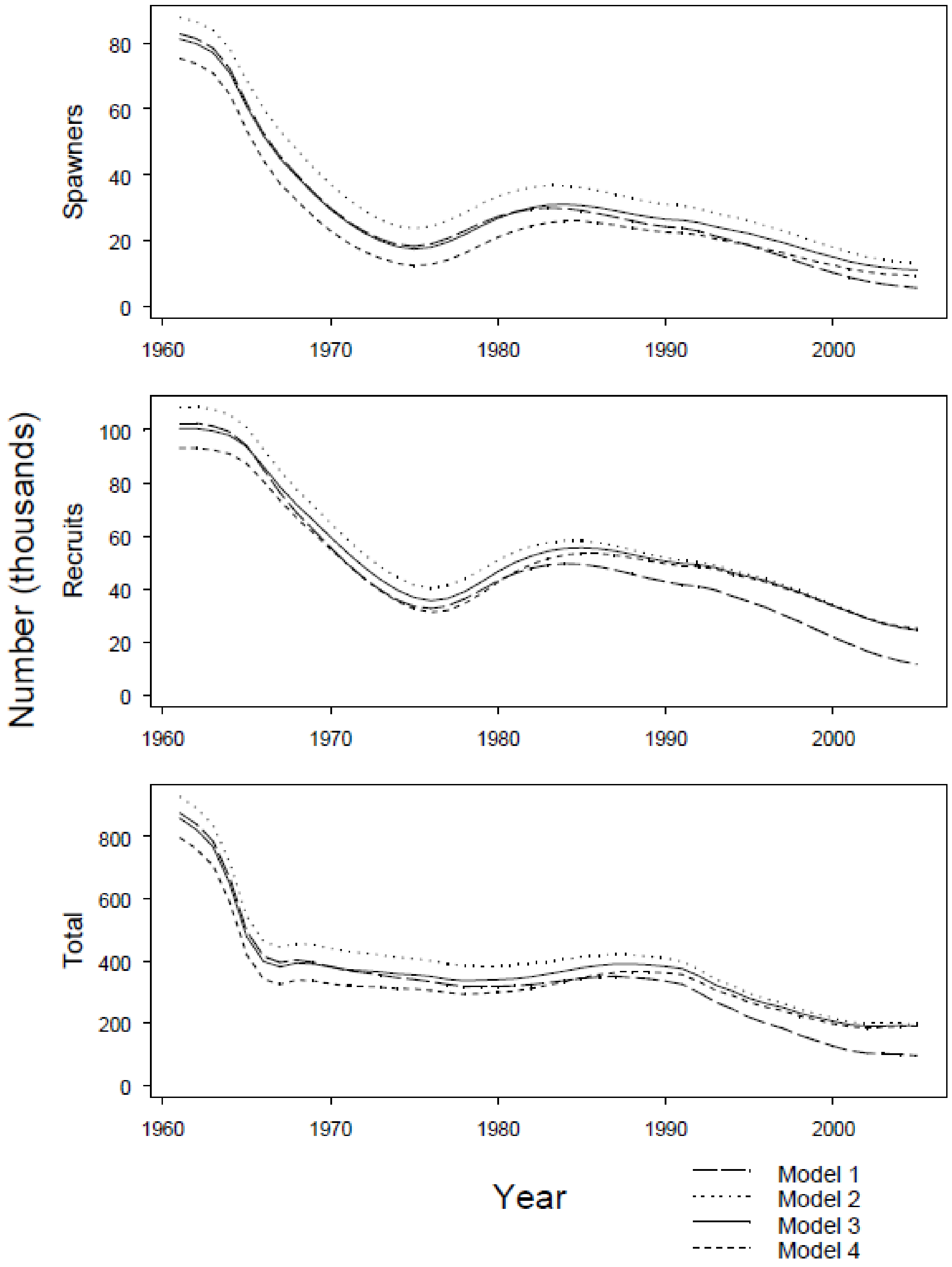
From Davis and Basson, 2012

Assessment Relative to Reference Points

AN EXCEPTIONALLY BRIEF INTRODUCTION

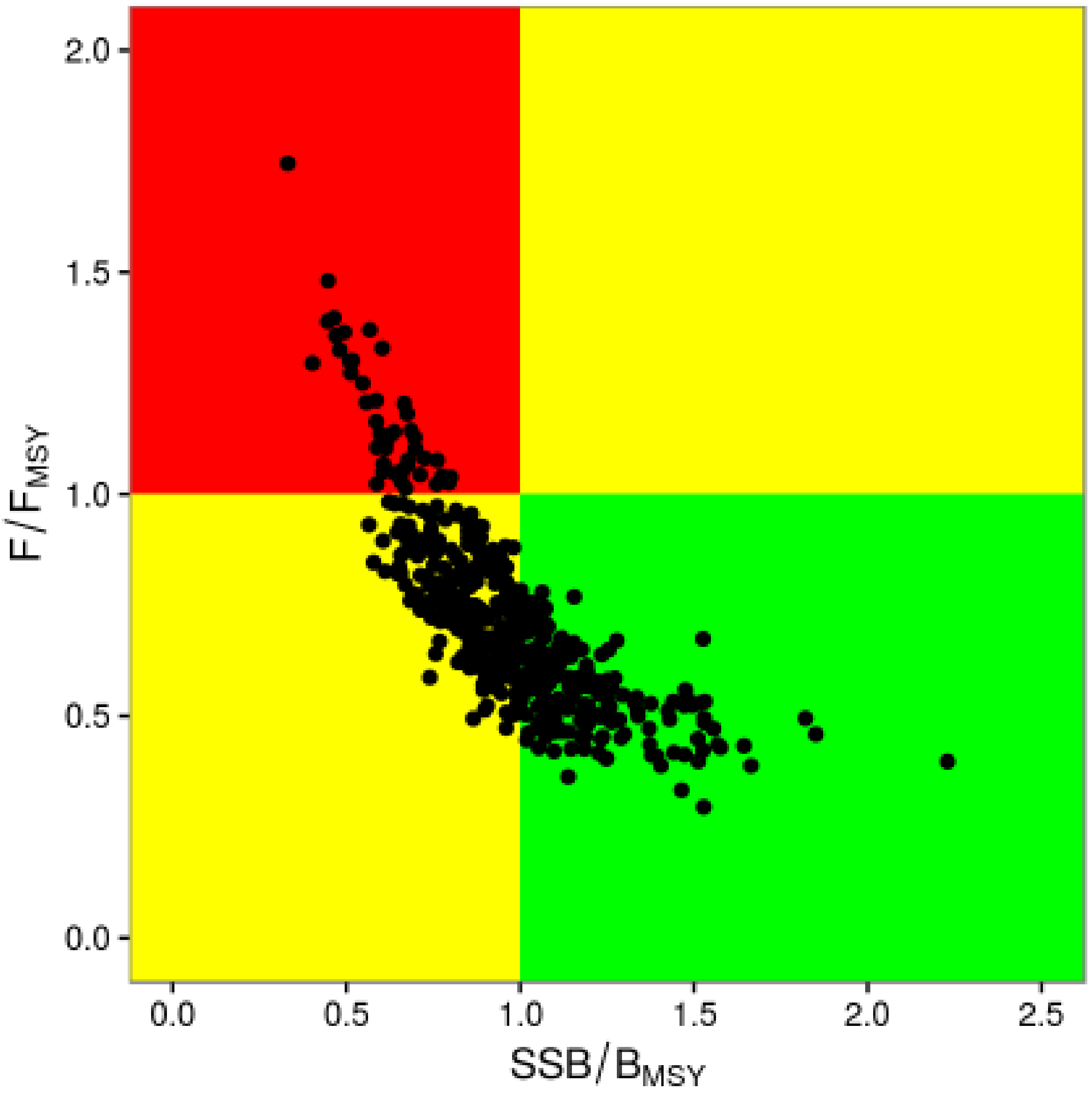
Interpreting Stock Assessments Relative to Reference Points: 1

- Various models are typically used to explain the observed data
  - Example from Porbeagle Shark
- Evaluate parameters, residuals, overall fit, residual deviance/AIC etc.
- Note that the model predictions typically lag by one year.
  - Assessment in **2020** using data until **2019**; but deriving advice for **2021**.



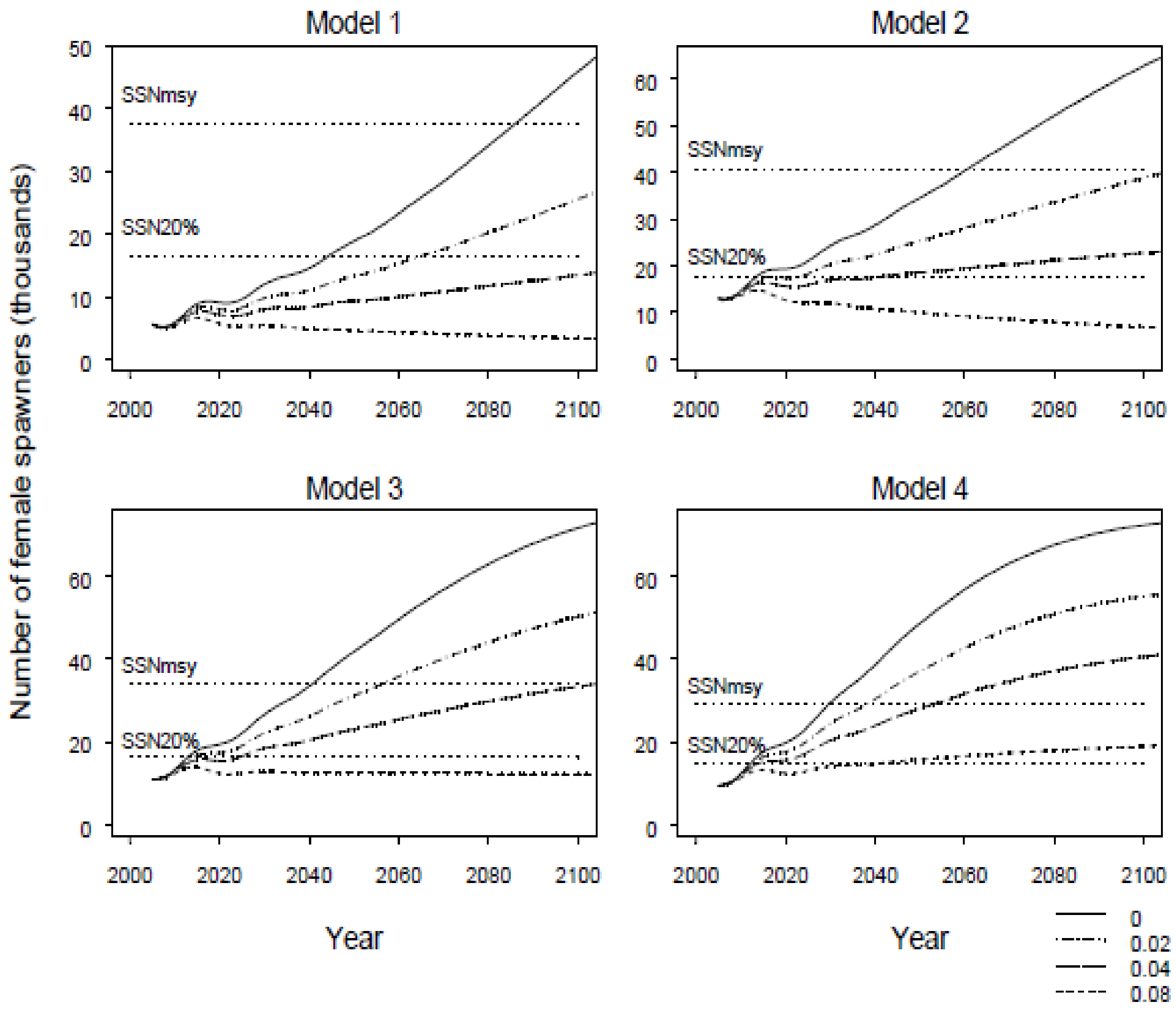
Interpreting Stock Assessments Relative to Reference Points: 2

- Evaluate the 'terminal year' predictions for F and SSB
  - How close/far are we from the reference point?
  - Example is relative to MSY
- From multiple models, this is done probabilistically:
  - Showing individual predictions of the stock and harvest
- This gives **Status** right now.
  - Probability overfished (**F** too high)
  - Probability of overfishing (**B** too low)



Interpreting Stock Assessments Relative to Reference Points: 3

- How do we set limits for the **future**?
- Make an assumption about removals in the current year (i.e. 2020)
- Project the population forward on the basis of its biology
  - Assuming different levels for F
- Determine how the predictions behave relative to reference points



Produce Probabilistic Catch Advice

- If we set TAC at level X, what is the likelihood that we would maintain the stock at an appropriate level?
  - Example is from Shortfin Mako in the North Atlantic
  - Managed relative to MSY (Fmsy and a proxy for Bmsy called SSFmsy)
  - Interesting characteristics:
    - Growth overfishing shown SSF table
    - Extremely long timelines for ‘recovery’ to MSY due to life history characteristics

A. Probability that $F < F_{MSY}$

TAC (t)	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	100	100	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100	100	100
200	100	100	100	100	100	100	100	100	100	100	100	100
300	100	100	100	100	100	100	100	100	100	100	100	100
400	100	100	100	100	100	100	100	100	100	100	100	100
500	96	99	100	100	100	100	100	100	100	100	100	100
600	81	89	99	99	98	96	95	97	97	97	96	95
700	57	69	93	92	88	82	80	83	84	85	82	82
800*	32	45	76	77	70	63	62	64	67	67	65	63
900	15	24	57	58	51	46	44	47	51	49	49	48
1000	5	11	37	38	31	27	26	28	30	31	30	30
1100	2	4	19	21	17	13	11	13	14	14	14	13

*Largest TAC interval with ≥ 50% by 2070

B. Probability that $SSF > SSF_{MSY}$

TAC (t)	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	46	42	24	14	11	33	53	60	63	67	72	81
100	46	42	24	13	10	29	49	56	59	61	66	73
200	46	42	24	13	9	26	47	54	55	57	61	66
300	46	42	24	12	9	22	42	50	52	53	56	60
400	46	42	24	12	8	19	39	47	49	50	52	55
500*	46	42	24	12	7	17	34	42	45	47	49	52
600	46	42	24	12	7	14	28	37	40	41	43	47
700	46	42	24	11	6	11	23	31	34	35	37	41
800	46	42	23	11	6	10	19	26	27	28	30	32
900	46	42	23	11	5	8	16	20	21	21	23	24
1000	46	42	23	11	5	7	12	16	16	15	15	17
1100	46	42	23	10	5	6	10	12	12	11	10	10

*Largest TAC interval with ≥ 50% by 2070

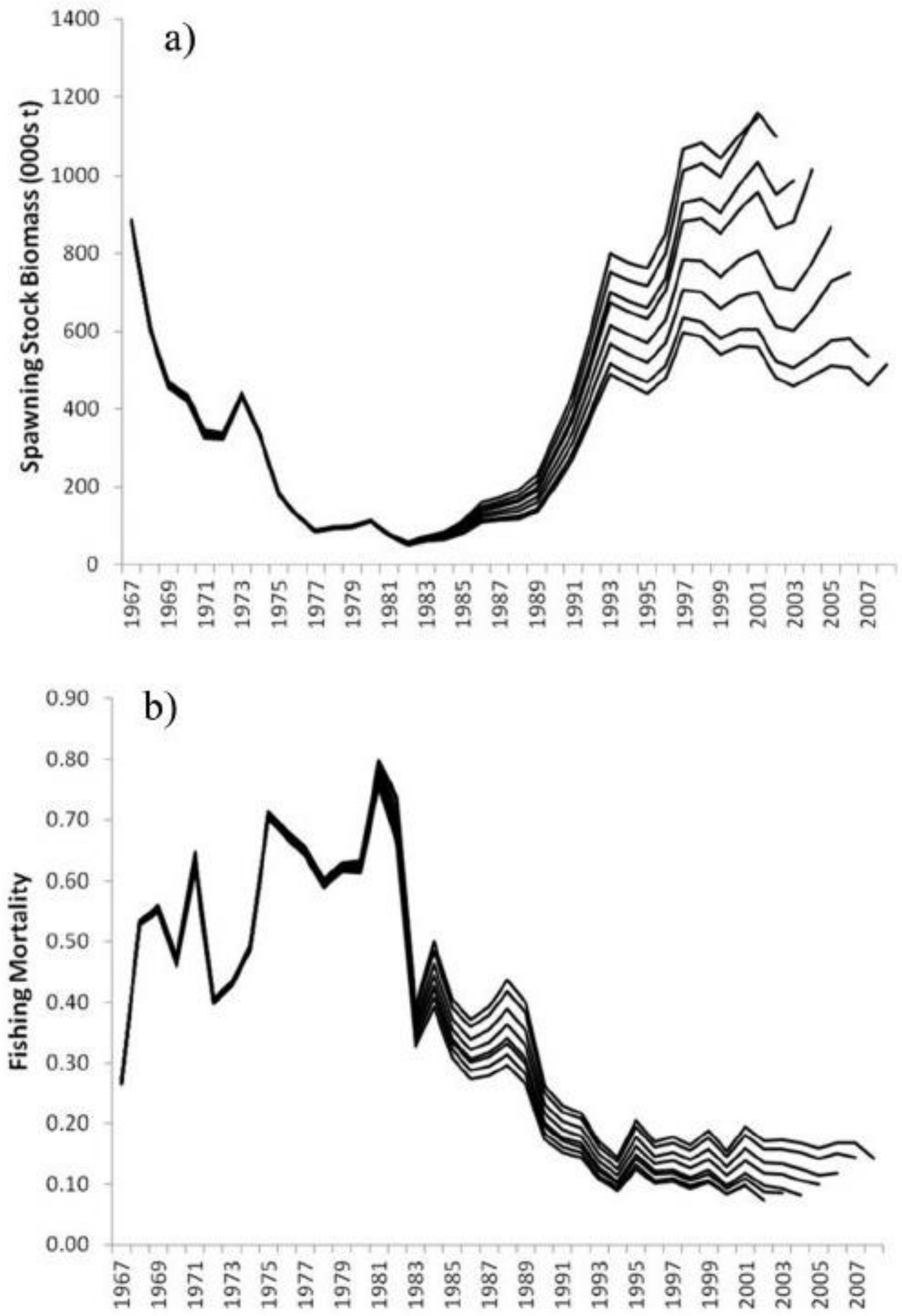
C. Probability of both $F < F_{MSY}$ and $SSF > SSF_{MSY}$

TAC (t)	2019	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
0	46	42	24	14	11	33	53	60	63	67	72	81
100	46	42	24	13	10	29	49	56	59	61	66	73
200	46	42	24	13	9	26	47	54	55	57	61	66
300	46	42	24	12	9	22	42	50	52	53	56	60
400	46	42	24	12	8	19	39	47	49	50	52	55
500*	46	42	24	12	7	17	34	42	45	47	49	52
600	45	42	24	12	7	14	28	37	40	41	43	47
700	41	41	24	11	6	11	23	31	34	35	37	41
800	27	34	23	11	6	10	19	26	27	28	30	32
900	14	21	23	11	5	8	15	20	21	21	23	24
1000	5	10	20	10	5	7	12	15	15	14	14	16
1100	2	4	14	9	4	5	7	9	9	8	8	8

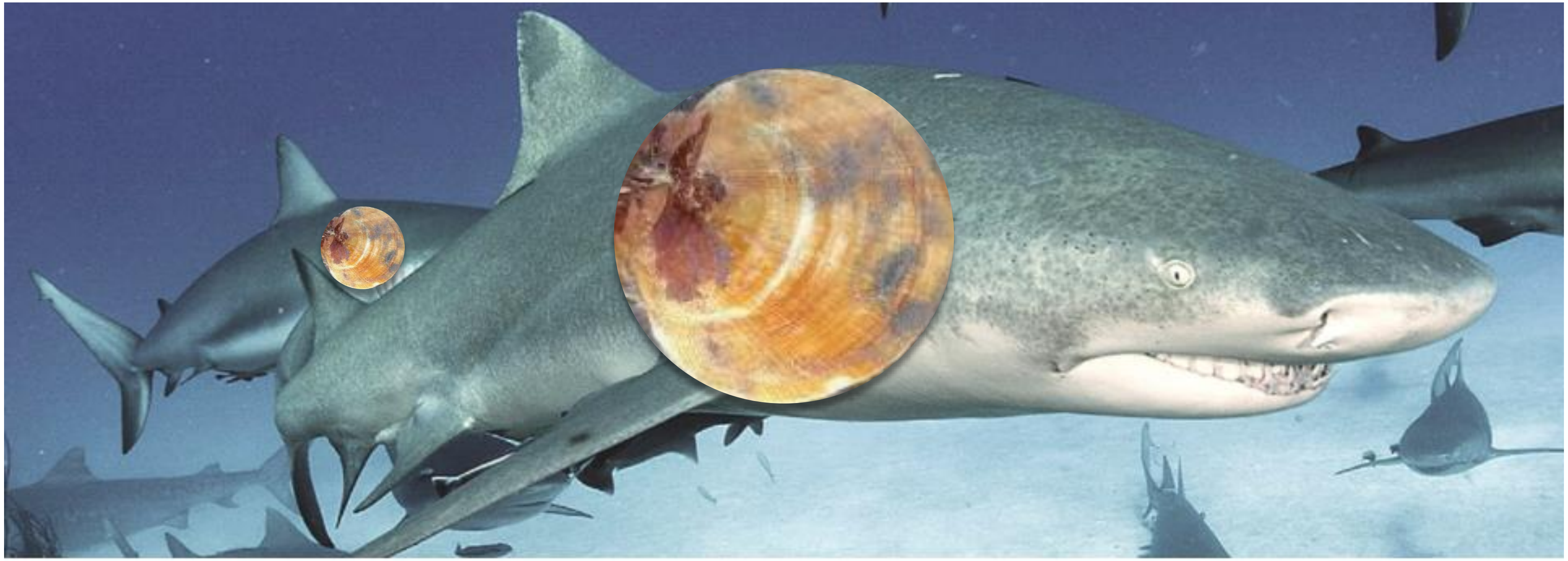
*Largest TAC interval with ≥ 50% by 2070

A Final Comment: Retrospective Patterns

- Very powerful diagnostic tool
  - Shows systematic bias in the estimate of biomass and fishing mortality
- Compare model fits as the terminal year of data is ‘peeled’ (i.e. remove 2019, then 2018, then….)
- Generally arise from:
  - Time-varying processes are unaccounted for
  - Data are contradictory or incomplete



Dusky Scallop Shark



Determine life history; sample some data; develop a model; account for F from removals; determine status; project future status relative to future potential catch.