Shifts in Fisheries Management: Adapting to Regime Shifts

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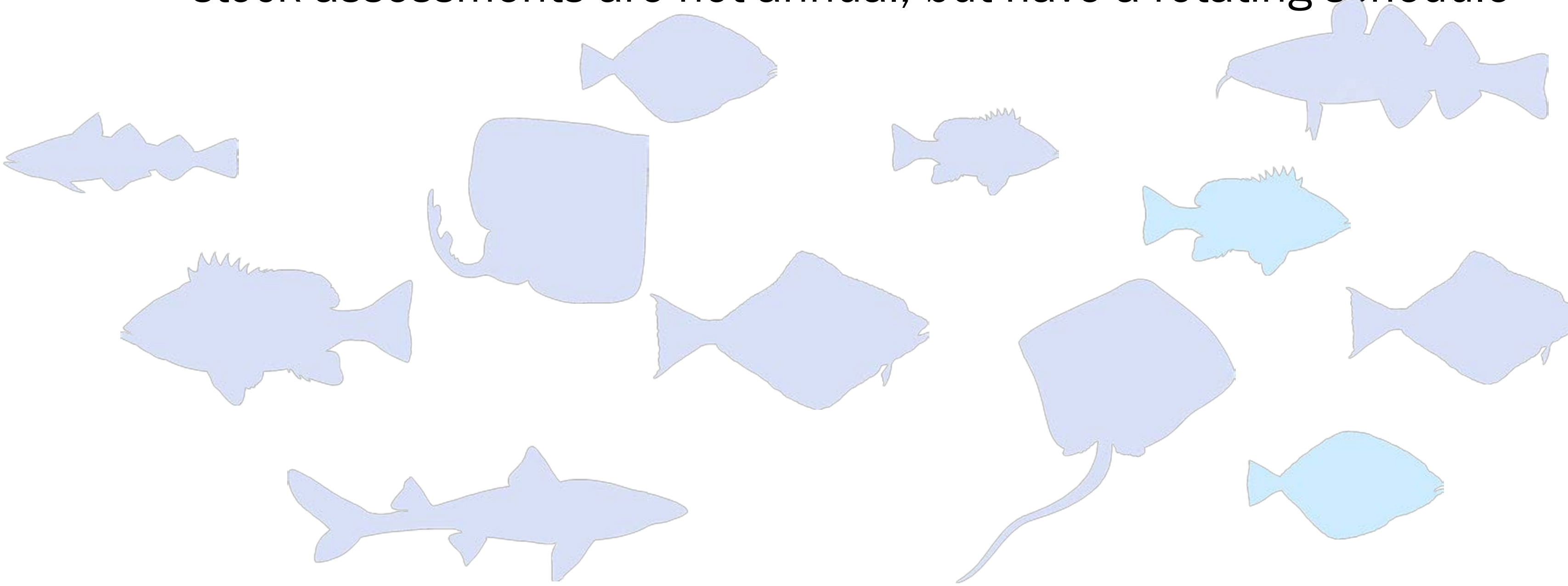
In press. Philosophical Transactions B

Regimes not Climate Change

- groundfish stock assessment
  - long-lived species with late-maturation (late entry to fisheries)
  - periods of correlated year class success
  - time-lag from regime-shift to year class entry to the fishery
- underlying ecosystem-state not annual change
  - some stability to the fishery
  - stock assessments are not annual, but have a rotating schedule



Confession: I am a fisheries scientist who believes

- Climate and ocean drivers (environmental forcing) impact fish populations and productivity
  - Use knowledge about the state of the environment to infer, predict, forecast the state of fish populations
  - Provide advice on fisheries quotas with incorporation of knowledge of the state of the environment
- Why the overall failure to provide fisheries advice, that is used to set quotas or manage fisheries, that incorporates environmental forcing?
- Need a ***tested*** decision-making framework that ***quantifies risks*** associated with harvest advice that incorporates environmental forcing

Confession: I had lost my way, but I have returned with enthusiasm

Fisheries Management and Ecology, 2006, **13**, 93–102

A framework for incorporating climate regime shifts into the management of marine resources

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Outline

1. Fisheries Science of Today
2. Ecosystem-based fisheries management
   a) Operationalized examples
   b) Environmental forcing in *single-species stock assessments*
   c) *Bottom-Up mechanistic models* linking climate change to environmental forcing to fish productivity
   d) Environmental forcing in the determination of *Harvest Control Rules*
3. Obstacles to Including Ecosystem-shifts and states into fisheries management
4. A Way Forward

Fisheries Science of Today

- in the last 20-30 years fisheries science has been evolving towards *ecosystem-based stock assessments and management*
  - overexploitation of some global fish stocks
    - focus of fisheries science on optimizing yield
    - deterministic models
    - non-precautionary decision-making frameworks scientific advice was not adhered to
  - global policies developed in 1990s
    - UN Conference on Environment and Development Agenda 21
    - UN Convention on Biological Diversity
    - 1995 FAO Code of Conduct for Responsibility
      - account for uncertainty in providing management advice by applying the precautionary approach

maximizing fisheries production

↓

conservation and risk management

Fisheries Science of Today

- fisheries science advice provides the possible consequences and the associated risk of various harvest strategies given the best estimates of current and projected stock and uncertainty

Table 6. Decision table with median posterior estimates of biomass after five years (B_{2016}) in relation to the target biomass (B_{MSY}) at various levels of constant annual total allowable catch (TAC). Probabilities (P) are presented for 4 stock status indicators: B_{2016} will be above the Limit Reference Point (40% of B_{MSY}), B_{2016} will be above the Upper Stock Reference (80% of B_{MSY}), B_{2016} will be above the target biomass of B_{MSY}, and B_{2016} will be above the current biomass (B_{2010}). For comparison purposes, median estimates of maximum sustainable yield for each area (in tonnes) are: 3C = 1390, 3D = 1888, 5AB = 1283, and 5CDE = 1091.

TAC (tonnes)	B_{2016}/B_{MSY}	$P(B_{2016} > 0.4B_{MSY})$	$P(B_{2016} > 0.8B_{MSY})$	$P(B_{2016} > B_{MSY})$	$P(B_{2016} > B_{2010})$
Area 3C					
0	1.20	0.94	0.73	0.61	0.69
500	1.15	0.89	0.69	0.57	0.57
1000	1.07	0.83	0.62	0.53	0.37
1500	0.97	0.76	0.58	0.48	0.24
2000	0.90	0.71	0.54	0.42	0.18
2500	0.79	0.66	0.50	0.39	0.12
3000	0.70	0.61	0.45	0.36	0.08
Area 3D					
0	1.60	1.00	0.95	0.91	0.58

Fisheries Science of Today

- success in identifying environmental forcing impacts on fish productivity
  - PICES has played a large role in this
- including environmental forcing when providing tactical advice (i.e. quotas, harvest strategies) has not been widespread
  - there are only a few examples where the relationship between environmental forcing and fish productivity have been operationalized and are used in fisheries management
    - California sardine stock assessment (regime-shift poster child)
    - Bering Sea and Aleutian Island crab stock assessment

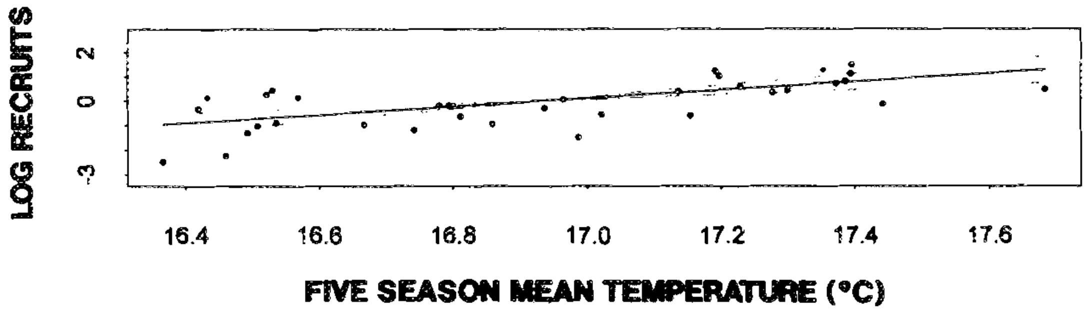
Ecosystem Approach to Fisheries

- ecosystem considerations in fisheries management
  - tactical advice – direct provision of management advice
    - total allowable catch
    - harvest rate
    - time-area closures
    - predefined management decisions – harvest control rules
  - strategic advice – management strategies tested through simulation; harvest policies
    - does the inclusion of ecosystem-state or environmental forcing improve the balance between yield and conservation?
    - what are the consequences of ignoring ecosystem-shifts or states when providing management advice?

Operationalized examples

1. Pacific sardine in the California Current System

$$\ln(R) = \alpha + f(T) + g(S) + \epsilon$$



Jacobson and MacCall. 1995. Can. J. Fish. Aquat. Sci. 52: 566-577

- since 1998, inclusion of SST (3 year mean from Scripps Pier) into the determination of the harvest control rule:
  - $HG_{2012} = (BIOMASS_{2011} - CUTOFF) \bullet F_{MSY} \bullet DISTRIBUTION$
  - $F_{MSY} = 0.25 \bullet T^2 - 8.19 \bullet T + 67.46;\ 0.05 \leq F_{MSY} \leq 0.15$

PFMC. 1998. Amendment 8 to the Northern Anchovy Fishery Management Plan

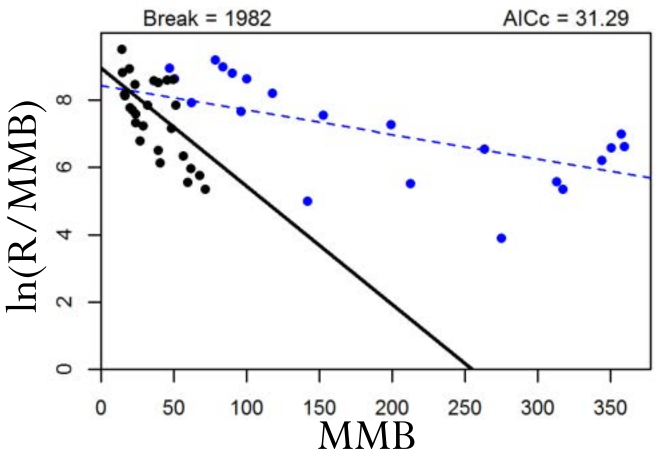
Hill et al. 2011. NOAA Tech. Memo 487

Operationalized examples

2. Eastern Bering Sea Tanner crab

   (Gulf of Alaska and Bering Sea Groundfish)

- dramatic change in productivity with 1977 regime-shift, with impacts 5 years later (time between spawning and recruitment to model size classes)



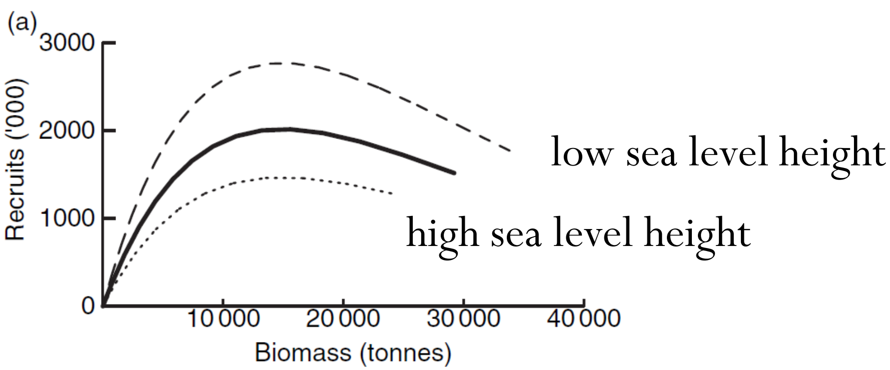
- OFL (and ABC) rely on $\overline{R}$ which is now set as $\overline{R}_{1982-present}$

Punt. 2012. NPFMC
Stockhausen et al. 2013. NPFMC

- (Groundfish OFL and ABC are based on recruitment estimates for the post-1977 period)

1. Environmental forcing into single-species assessments

- *Stock-recruitment Relationship* with environmental forcing – e.g. Pacific cod



$$R_t = s_0 B_t e^{(-\beta B_t)} e^{(\phi_t)} e^{\delta v_t}$$

annual deviation in sea level height

*Sinclair and Crawford. 2005. Fish. Oceangr. 14: 138-150
*Schirripa et al. 2009. ICES J. Mar. Sci 66: 1605-1613
*Jacobson and MacCall. 1995. Can. J. Fish. Aquat. Sci. 52: 566-577
MacKenzie and Koster. 2004. Ecol. 85: 784-794
Chen and Irvine. 2001. Can. J. Fish. Aquat. Sci. 58: 1178-1186
Ottersen et al. 2006. Fish. Oceangr. 15: 230-243
Clark et al. 2003. Glob. Change Biol. 9: 1669-1680

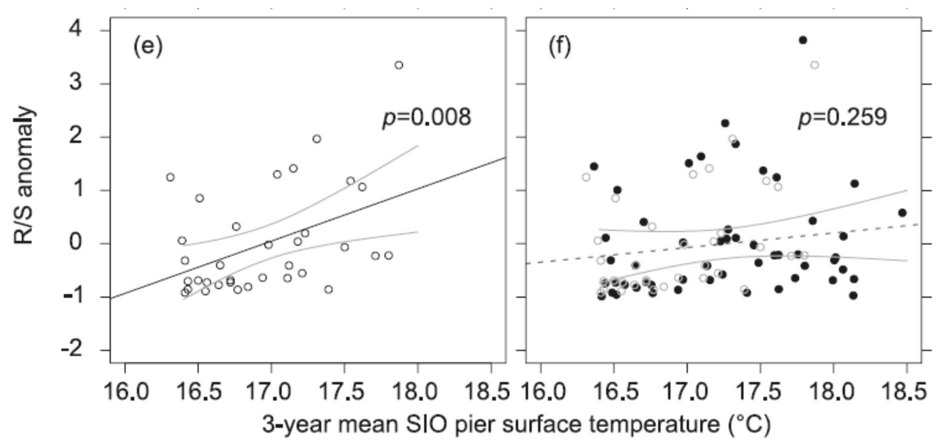
1. Environmental forcing into single-species assessments

- *Stock-recruitment Relationship* with environmental forcing
  - these relationships can be spurious correlations that eventually break down

    Myers. 1998. Rev. Fish. Bio. Fish. 8: 285-305.
  - in part due to fishing-induced impacts on spawning biomass and recruitment coincident with a directional change in the environment

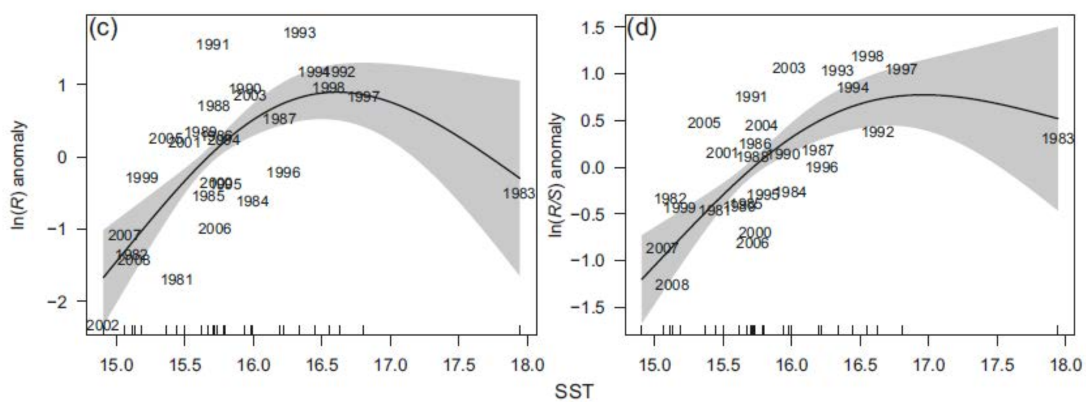
    Haltuch & Punt. 2011. Can. J. Fish. Aquat. Sci. 68: 912-926

Breakdown of Pacific sardines



- update the S-R to SST relationship – no longer significant

  McClatchie et al. 2010. Can. J. Fish. Aquat. Sci. 67: 1782-1790.
- SST removed from sardine HCR in 2012



- that update was actually not correct – spawning area SST better
- constantly revisit and update relationships

  Lindegren & Checkley. 2013. Can. J. Fish. Aquat. Sci. 70: 245-252
- confidence eroded – difficult now to re-instate SST linked HCR

1. Environmental forcing into single-species assessments

- *Stock-recruitment Relationship* with environmental forcing
  - synchronous shifts in recruitment across Large Marine Ecosystems coincident with regime-shifts
    - not due to increase in spawning stock
    - obvious and strong evidence for regime-shift forcing on recruitment

      Szuwalski et al. *In press*. Proc. Nat. Acad. Sci.
  - recent analyses illustrate that environmental forcing is indeed a stronger influence on recruitment than spawning stock biomass

    Vert-pre et al. 2013. Proc. Nat. Acad. Sci. 110: 1779-1784.

Table 1. Percentage of stocks and number of stocks that are best explained by each hypothesis and the total AICc weight for each

Hypothesis	Stocks with the highest support	No. of stocks best supported	Total AICc weight	Stocks best supported after correction for estimation bias
Abundance	18.3%	37	16.1%	24%
Regimes	38.6%	95	41.3%	27%
Mixed	30.5%	65	28.3%	45%
Random	12.6%	33	14.3%	4%

1. Environmental forcing into single-species assessments

- ecosystem-shifts and states also impact other biological parameters:
  - growth
    - very few stock assessments with time-varying growth but this avenue could be expanded to include environmental forcing
    - environmental forcing on growth will be both indirect impacts (e.g. prey availability) and direct impacts (e.g. physiological) which can have counfounding consequences
    - so unless a large portion of the variability is due to direct impact, these avenues of investigation will non likely provide better results than environment-recruitment studies

1. Environmental forcing into single-species assessments

- ecosystem-shifts and states also impact other biological parameters:
  - catchability
    - environmental forcing can impact catchability through behavioural changes such as feeding habits, densities or spatial distribution

      Zielger et al. 2003. Fish. Res. 61: 107-123

      Maynou and Sarda. 2001. ICES J. Mar. Sci. 58: 1318-1325

      Stoner. 2004. J. Fish. Bio. 65: 1445-1471
    - time-varying catchability is seldom included in stock assessments despite proposed methods to model environmental forcing impacts on catchability

      Freon. 1995.

      Maunder and Watters. 2003. Fish. Bull. 101: 89-99
    - temperature as a covariate for survey catchability in Bering Sea flathead sole stock assessment (Stockhausen et al. 2012. NPFMC)
    - did not improve model fit for Atlantic cod (Swain et al. 2000. ICES J. Mar. Sci. 57: 56-68)

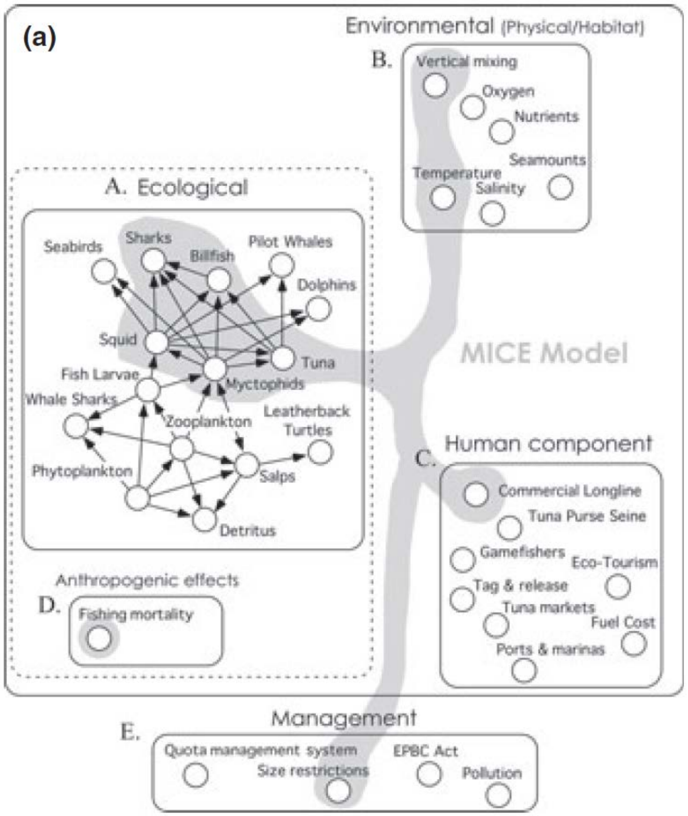
2. Bottom-up Mechanistic Models

- Linking climate to Environmental Forcing to Fish Productivity
  - integrating:
    - outputs of Global Climate Models
      - exclusion of low-frequency climate variability and focus on projections that are at least 30 years from current
    - into Regional Oceanographic Models
    - and end-to-end biological models
      - would require multi-species fisheries assessment for full ecosystem-based implementation

      Hollowed et al. 2011. Fish and Fisheries 12: 189-208
  - cannot provide tactical advice for the short-term (even up to 10-year forecasting)
  - can provide strategic advice for adaptive and mitigation planning for the long-term
  - complexity may translate to compounded uncertainty which would not necessarily reduce risk in tactical advice

2. Bottom-up Mechanistic Models

- Linking climate to Environmental Forcing to Fish Productivity
  - Models of Intermediate Complexity for Ecosystem assessments



- intermediate to single-species assessments and the whole integrated ecosystem models with climate-ocean forcing
- limit complexity by selecting only the ecosystem components that are required to address the main impacts of the management question under consideration
- eg. tuna, sharks, billfish in LL fishery of Coral Sea
- capable of providing tactical advice

Plaganyi et al. 2014. Fish and Fisheries 15: 1-22

- yet to be applied

3. Determination of Harvest Control Rules

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A framework for incorporating climate regime shifts into the management of marine resources

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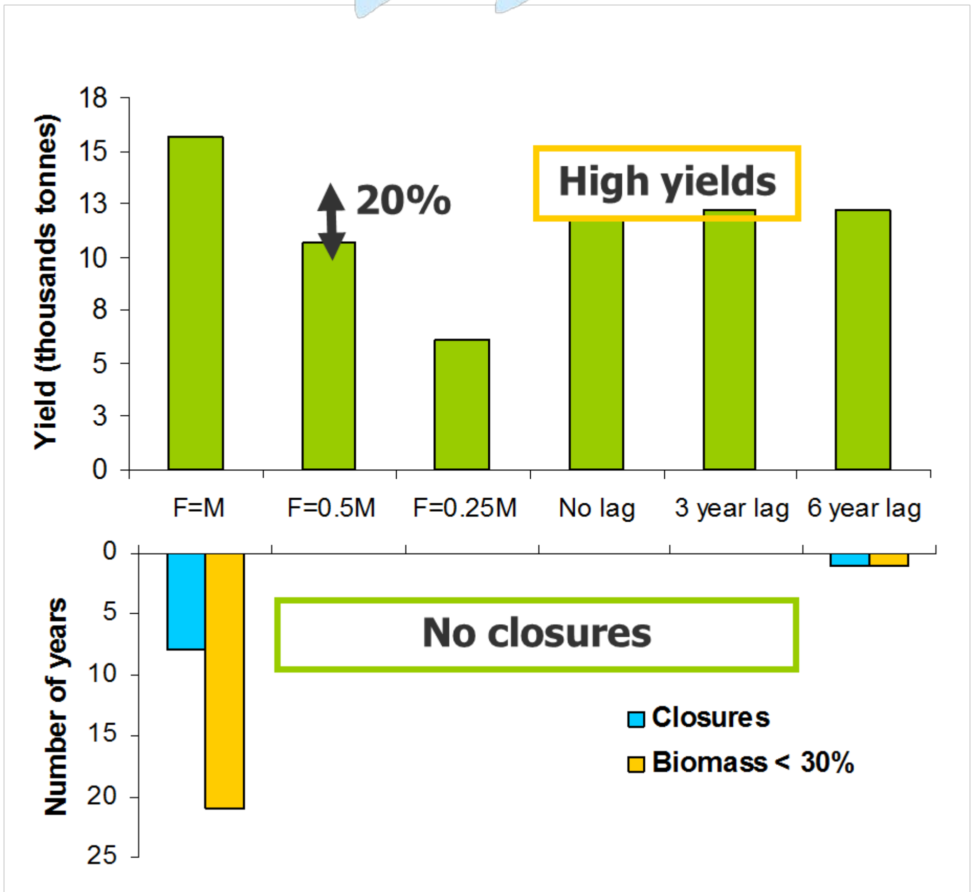
- Regime-specific harvest control rules
  - Productivity linked
    - Regime 1: good productivity => F=M
    - Regime 2: poor productivity => F=0.25M
    - Regime 3: moderate productivity => F=0.5M
- When to change harvest rates?
  - when the regime occurs
  - delayed by the age at maturity (3 or 5 years)
  - delayed by twice the age at maturity (6 or 10 years)

3. Determination of Harvest Control Rules

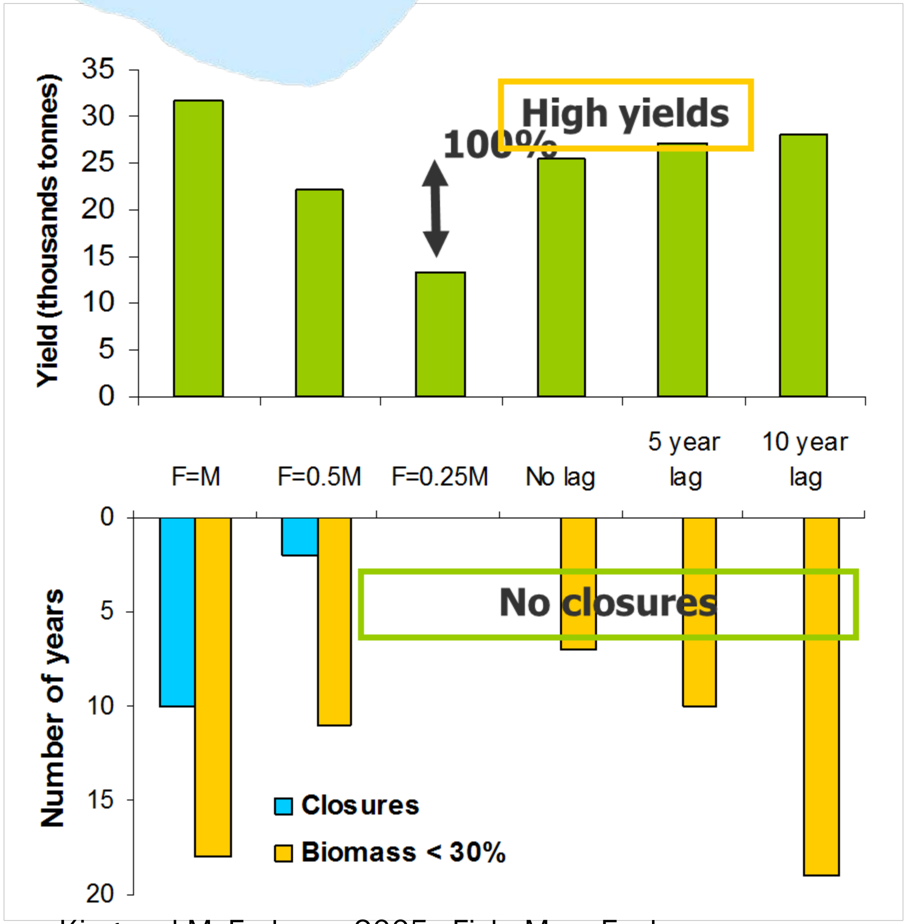
- Short-lived species: benefits and trade-offs



King and McFarlane. 2005. Fish. Man. Ecol.

3. Determination of Harvest Control Rules

- Long-lived species: benefits and trade-offs



King and McFarlane. 2005. Fish. Man. Ecol.

3. Determination of Harvest Control Rules

- Multi-species: benefits and trade-offs

C. Fu et al. / Progress in Oceanography xxx (2013) xxx–xxx

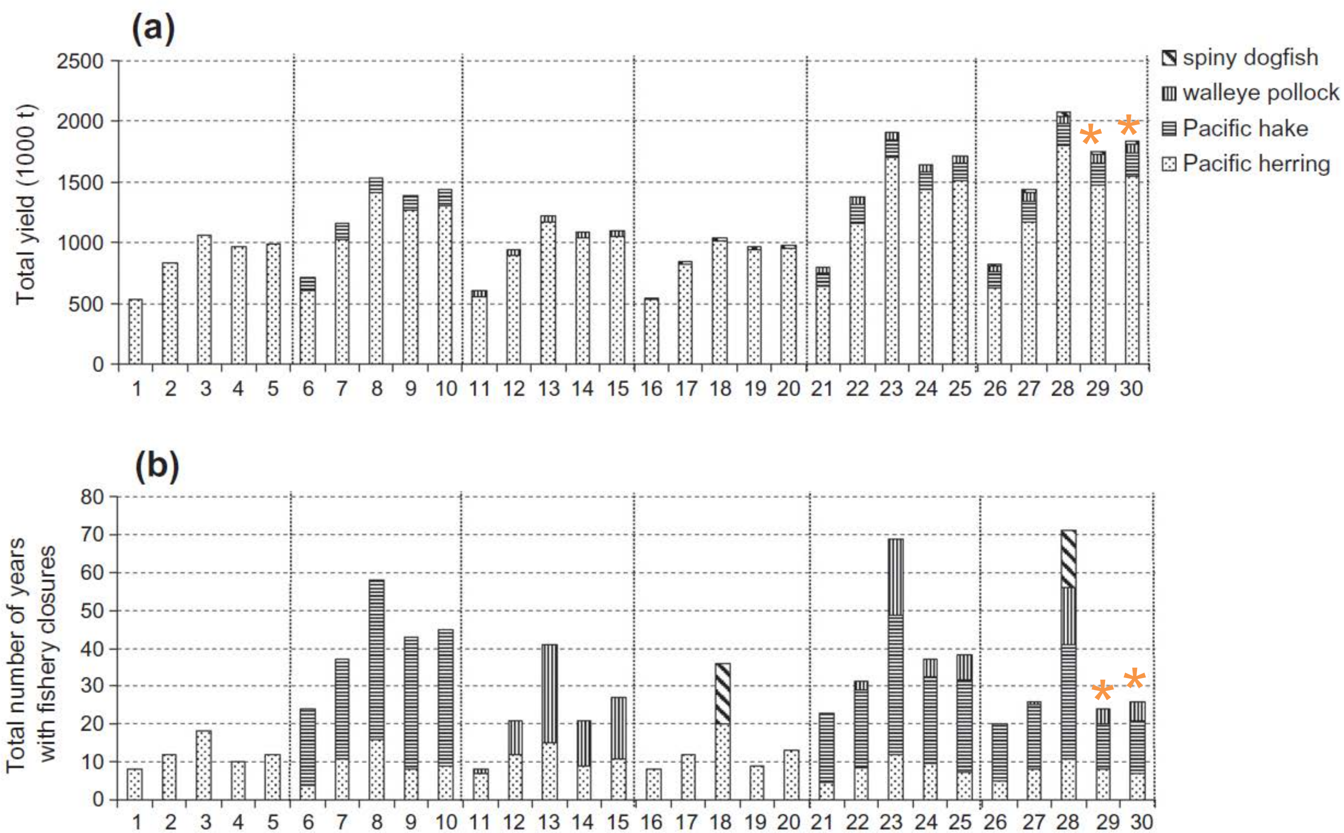
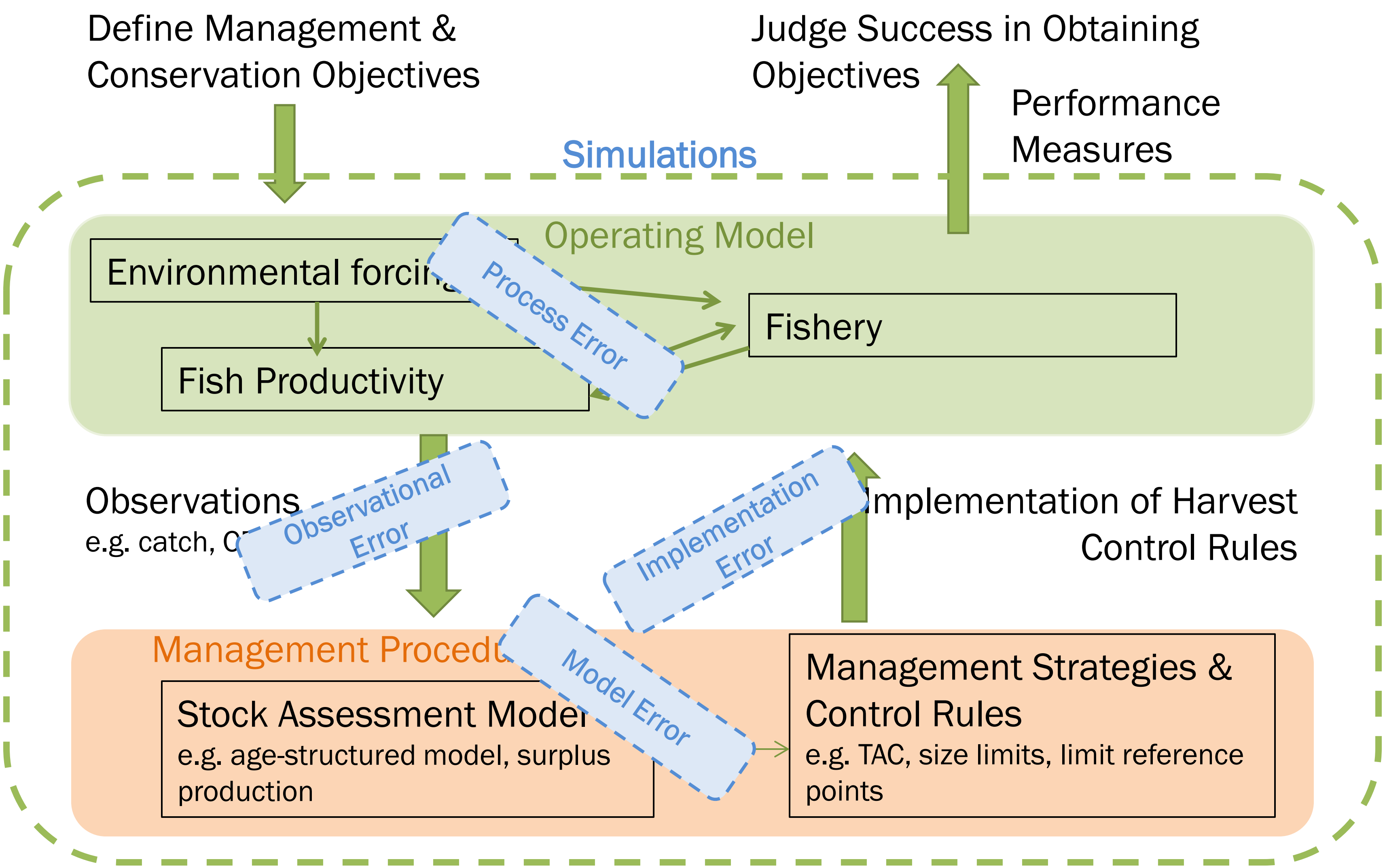


Fig. 3. Total yield (a) and number of years with fishery closures (b) for the identified species under 30 different fishing scenarios (Table 3).

3. Determination of Harvest Control Rules

Management Strategy Evaluation



3. Determination of Harvest Control Rules

- *Dynamic* B_0 approach
  - projects popn forward from first year with catches but without fishing to estimate B_0
    - time-varying recruitment, growth and natural mortality which can be simulated with regime-like characteristics

      MacAll et al. 1985. CalCOFI Rep. 26: 119-129
- *Moving window* approach
  - estimates B_0 and B_{MSY} using recruitment estimates for a specified number of years (length of regime)

    Punt et al. 2013. ICES J. Mar. Sci
- *STARS* approach
  - detects regime-shifts based on user-defined minimum duration and a *t*-test
  - time series then separated into regime-states to define regime-specific recruitment or estimation of reference points

    Rodionov & Overland. 2005. ICES J. Mar. Sci. 62: 328-332

3. Determination of Harvest Control Rules

Regime-specific harvest control rules

- Haltuch et al. 2009. Fish. Res. 100: 42-56
  - MSE for rockfish, flatfish and Pacific hake
    - *better to use average* B_0
    - based on a standard stock-recruitment relationship
    - catch and survey time series *need to span a full environmental cycle*
- Szuwalski & Punt. 20012. ICES J. Mar. Sci.
  - MSE for snow crab
    - regime-based HCR has a *higher probability of overfishing*
    - identifying changes in productivity that are definitely driven by environmental regimes rather than fishing pressure remains the highest obstacle
- Amar et al. 2009. Can. J. Fish. Aquat. Sci. 66: 2222-2242
  - MSE for walleye pollock
    - regime-specific HCR did have higher yields but also *higher risk of overfishing* since spawning biomass was maintained at a lower level

Obstacles

1. linkages between environmental variables and recruitment eventually break down, either due to spurious correlations or changes in the nature of the relationship
   - potentially true for long-term climate change
2. typically the length of recruitment time series is shorter than the span of at least one regime-shift and state
   - too short to characterize the nature of climate-change impacts
3. without a reliable way to quickly identify a regime-shift, predictions (even short-term) are not possible
4. environmental and recruitment time series typically have high within-regime variability which makes it difficult for stock assessments to detect regime-shifts

- error inherent in environmental, recruitment, catch and stock assessment models are currently such that little, or nothing, is gained by including regime-states into fisheries management advice

A Way Forward

"The transition to EBFM should be evolutionary not revolutionary"

Marasco et al. 2007. Can. J. Fish. Aquat. Sci. 64: 928-939.

- Did we try too much too soon ?
- Are the managers doubtful of the benefits ?
- Current attempts should not focus on directly integrating regime-shifts and states into stock assessments or in estimating biological reference points
  - but rather ecosystem states and shifts are used as supporting information to stock assessment advice

A Way Forward

- Stock assessment models are projected forward 5-10 years to provide decision makers risks of various tactical advice

Table 6. Decision table with median posterior estimates of biomass after five years (B_{2016}) in relation to the target biomass (B_{MSY}) at various levels of constant annual total allowable catch (TAC). Probabilities (P) are presented for 4 stock status indicators: B_{2016} will be above the Limit Reference Point (40% of B_{MSY}), B_{2016} will be above the Upper Stock Reference (80% of B_{MSY}), B_{2016} will be above the target biomass of B_{MSY}, and B_{2016} will be above the current biomass (B_{2010}). For comparison purposes, median estimates of maximum sustainable yield for each area (in tonnes) are: 3C = 1390, 3D = 1888, 5AB = 1283, and 5CDE = 1091.

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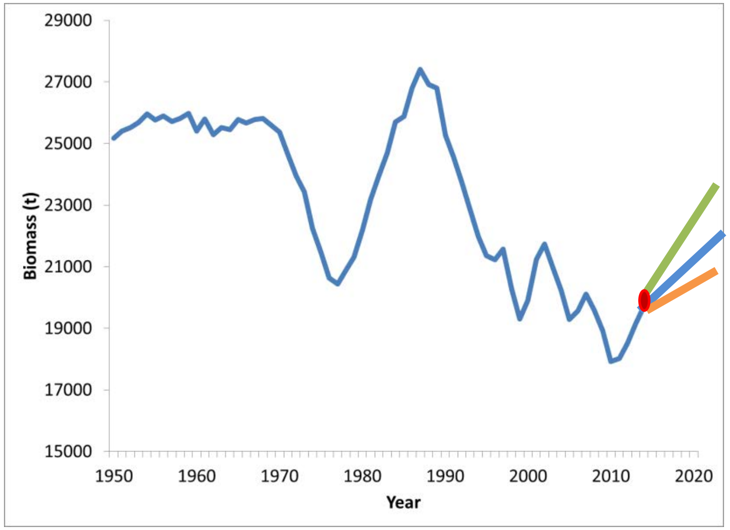
- those projections are based on *CURRENT (average)* conditions
  - what if they are projected under separate scenarios for productivity?
    - low recruitment; average recruitment; high recruitment

A Way Forward

Stock Assessment



Decision Table

TAC	Low		Average		High	
	B_{2014}/B_{MSY}	$P(B_{2020} > B_{MSY})$	B_{2014}/B_{MSY}	$P(B_{2020} > B_{MSY})$	B_{2014}/B_{MSY}	$P(B_{2020} > B_{MSY})$
0	0.97	0.55	1.20	0.61	1.30	0.81
500	0.90	0.50	1.15	0.57	1.25	0.77
1000	0.85	0.45	1.07	0.53	1.15	0.73
1500	0.80	0.40	0.97	0.48	1.10	0.68

State of the Ecosystem

	2010-2015 Mechanistic Association to Recruitment
Climate	Low year class success
Oceangr	Low year class success
Prey	Average juvenile survival

Additional information to managers on where to pick from the decision table

Use of plausibility ranking schemes

A Way Forward

- still requires conceptual mechanisms linking ecosystem state to productivity
- can utilize a suite of environmental drivers
  - will this help when proxies break down?
  - builds on efforts for State of the Ecosystem and Indicator projects
- decouples complete reliance on relationship to environmental drivers
  - conflicting signals could go with default scenario that would have been used without ecosystem information
- ecosystem information sits next to socio-economic considerations in decision-making
  - decision-makers select the acceptable uncertainty and risk along with all contexts
- *"They feel engaged and not threatened" W4 on Sunday*
  - *evoluntionary not revolutionary*

- still needs to be framed into a decision analysis within a Management Strategy Evaluation

Incorporating Ecosystem Considerations into Tactical Advice

1. global expectation that stock assessment advice is based on precautionary approach, account for all uncertainty and consider ecosystem impacts on fish productivity
2. fisheries agencies have mandates to implement ecosystem-based fisheries management
3. frame fish productivity into regime-specific states to inform the projection of recruitment
4. still needs to be done within a decision analysis framework
    - to date, the 'best case' forecasts have been unreliable and may in the longer term lead to a loss in confidence that accounting for ecosystem factors is worthwhile
    - Does ignoring environmental impacts lead to poor performance?
    - Can we do better using an environmental control?