Including regime shifts in fisheries assessments and harvest recommendations using Markov switching models

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Acknowledgements

Jim Thorson (NOAA-NWFSC)

Cody Szuwalski (UC Santa Barbara)

Curry Cunningham (U Washington)

UMass | Dartmouth

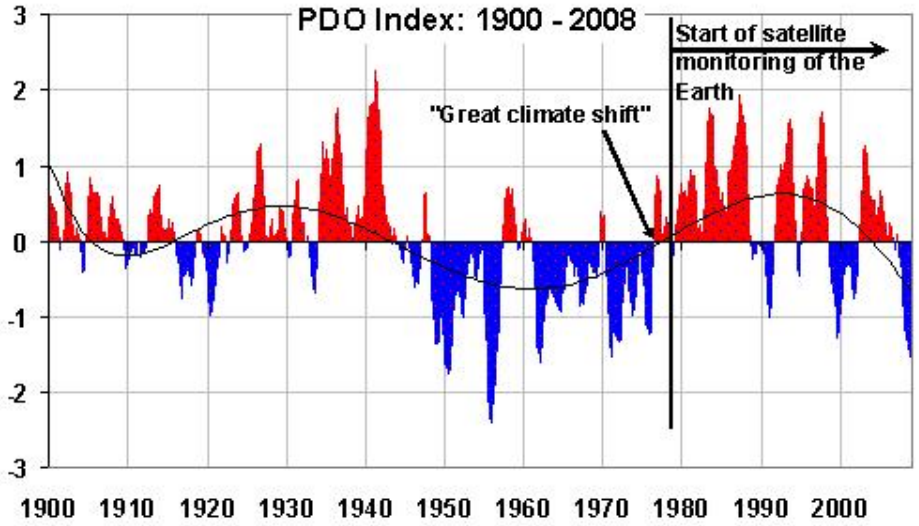
DFO Seminar: 15th October 2014

Seminar outline

- Regime shifts in Marine Ecosystems
- Providing management advice with regimes
- Markov switching models (or HMMs)
- Estimating regime shifts using HMMs
- Application to New England fisheries
- Extensions to the approach
- Further work

Regime Shifts

Ubiquitous in the ecological and fisheries literature



Pergamon

Progress in Oceanography 47 (2000) 103–145

Progress in Oceanography

www.elsevier.com/locate/pocean

Empirical evidence for North Pacific regime shifts in 1977 and 1989

Steven R. Hare [a,*], Nathan J. Mantua [b]

[a] International Pacific Halibut Commission, P.O. Box 95009, Seattle, WA 98145-2009, USA
[b] Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Box 354235, Seattle, WA 98195-4235, USA

OPEN ACCESS Freely available online

PLoS one

Regime Shifts and Weakened Environmental Gradients in Open Oak and Pine Ecosyste

Brice B. Hanberry[1]*, Dan C. Dey[2], Hong S. He[1]

1 Department of Forestry, University of Missouri, Columbia, Missouri, United States of America

ICES Journal of Marine Science, 62: 1205–1215 (2005)
doi:10.1016/j.icesjms.2005.04.024

PNAS

Newly discovered landscape traps produce regime shifts in wet forests

David B. Lindenmayer[a,1], Richard J. Hobbs[b], Gene E. Likens[a,c,1], Charles J. Krebs[d], and Samuel C. Banks[a]

[a]Fenner School of Environment and Society, Australian National University, Canberra ACT 0200, Australia; [b]School of Plant Biology, University of West Australia, Crawley, Western Australia 6009, Australia; [c]Cary Institute of Ecosystem Studies, Millbrook, NY, 12545; and [d]Department of Zoology, Universi British Columbia, Vancouver, BC, Canada V6T 1Z4

Contributed by Gene E. Likens, August 4, 2011 (sent for review May 28, 2011)

Synchronous ecological regime shift and the North Sea in the late 1980s

Annu. Rev. Ecol. Evol. Syst. 2004. 35:557–81
doi: 10.1146/annurev.ecolsys.35.021103.105711

First published online as a Review in Advance on August 5, 2004

ELSEVIER

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolec

Survey

Regime shifts and management

Anne-Sophie Crépin [a,b,*], Reinette Biggs [b], Stephen Polasky [a,c], Max Troell [a,b]

[a] *The Beijer Institute of Ecological Economics, Sweden*

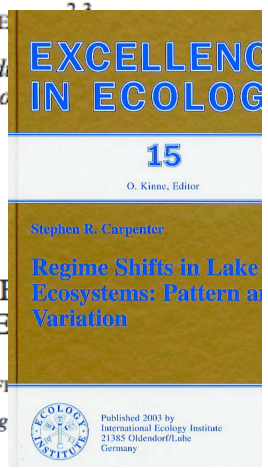
Regime Shifts, Resilience, and Biodiversity in Ecosystem Management

Carl Folke,[1,2] Steve Carpenter,[2,3] Brian Walker,[4]
Marten Scheffer,[5] Thomas Elmqvist,[1] Lance Gund

Interacting regime shifts in ecosystems: implication for early warnings

W. A. Brock[1] and S. R. Carpe

Department of Economics, University of Wisconsin, Madi
[2]Center for Limnology, University of Wisconsin, Madis



Catastrophic regime shifts in ecosystems: linking theory to observation

Marten Scheffer[1] and Stephen R. Carpenter[2]

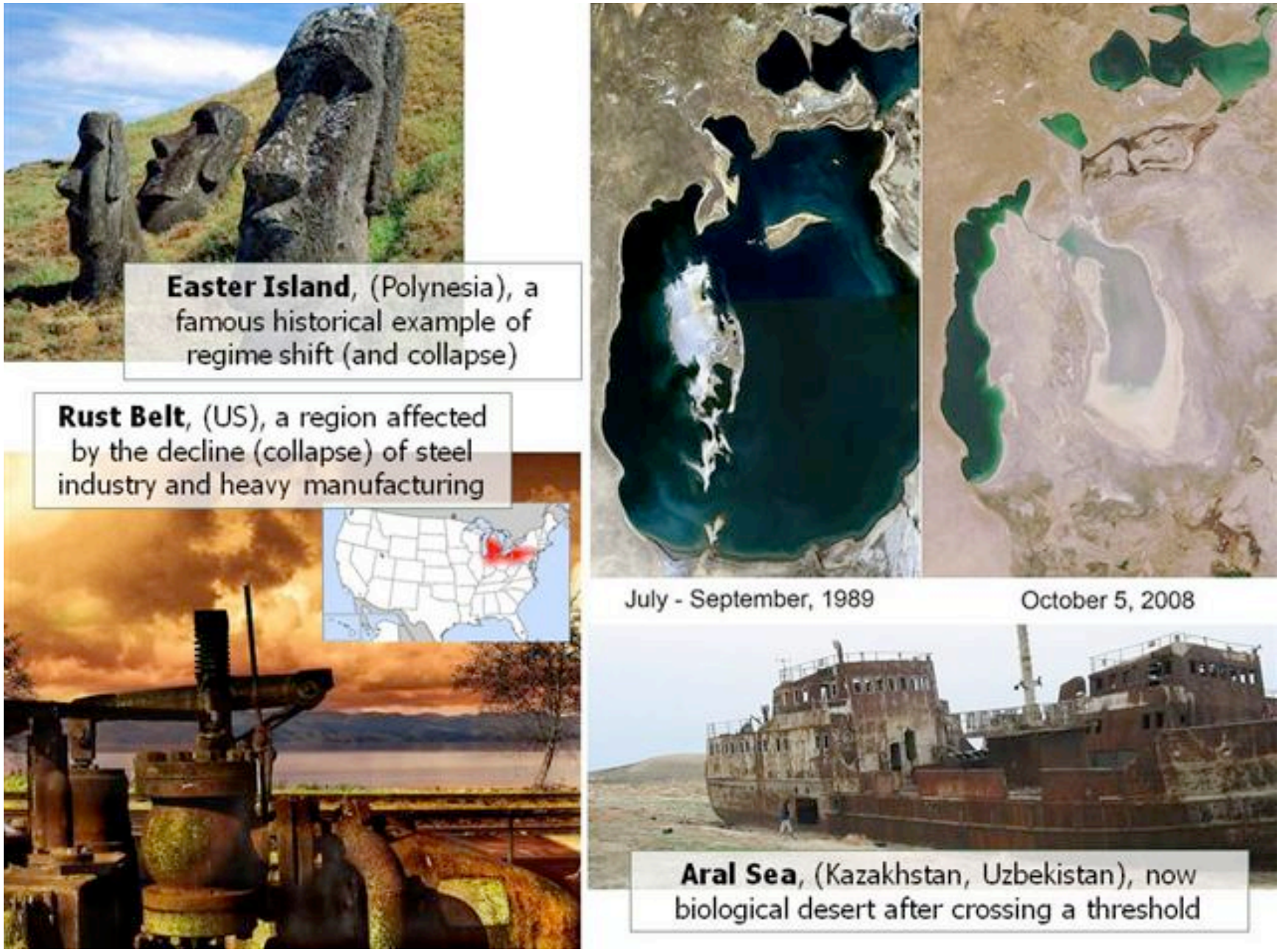
[1]Department of Aquatic Ecology and Water Quality Management, Wageningen University, PO Box 8080, 67
The Netherlands
[2]Center for Limnology, University of Wisconsin, 680 North Park Street, Madison, WI 53706, USA

Ecology, 86(7), 2005, pp. 1797–1807

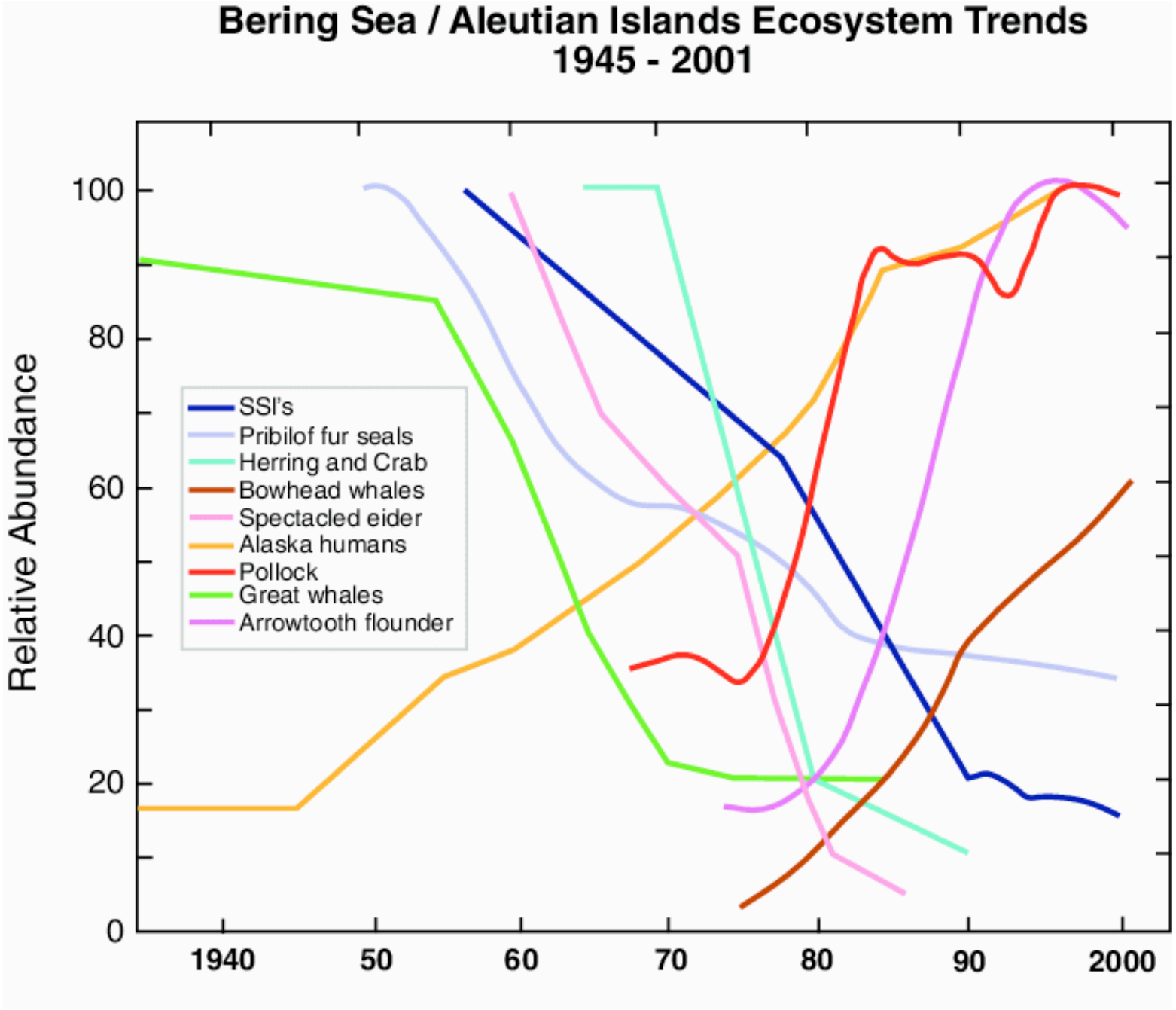
IMPLICATIONS OF SPATIAL HETEROGENEITY F REGIME SHIFTS IN ECOSYSTE

Egbert H. van Nes[1] and Marten Scheff

Department of Aquatic Ecology and Water Quality Management, Wagening
NL-6700 DD Wageningen, The Netherlands

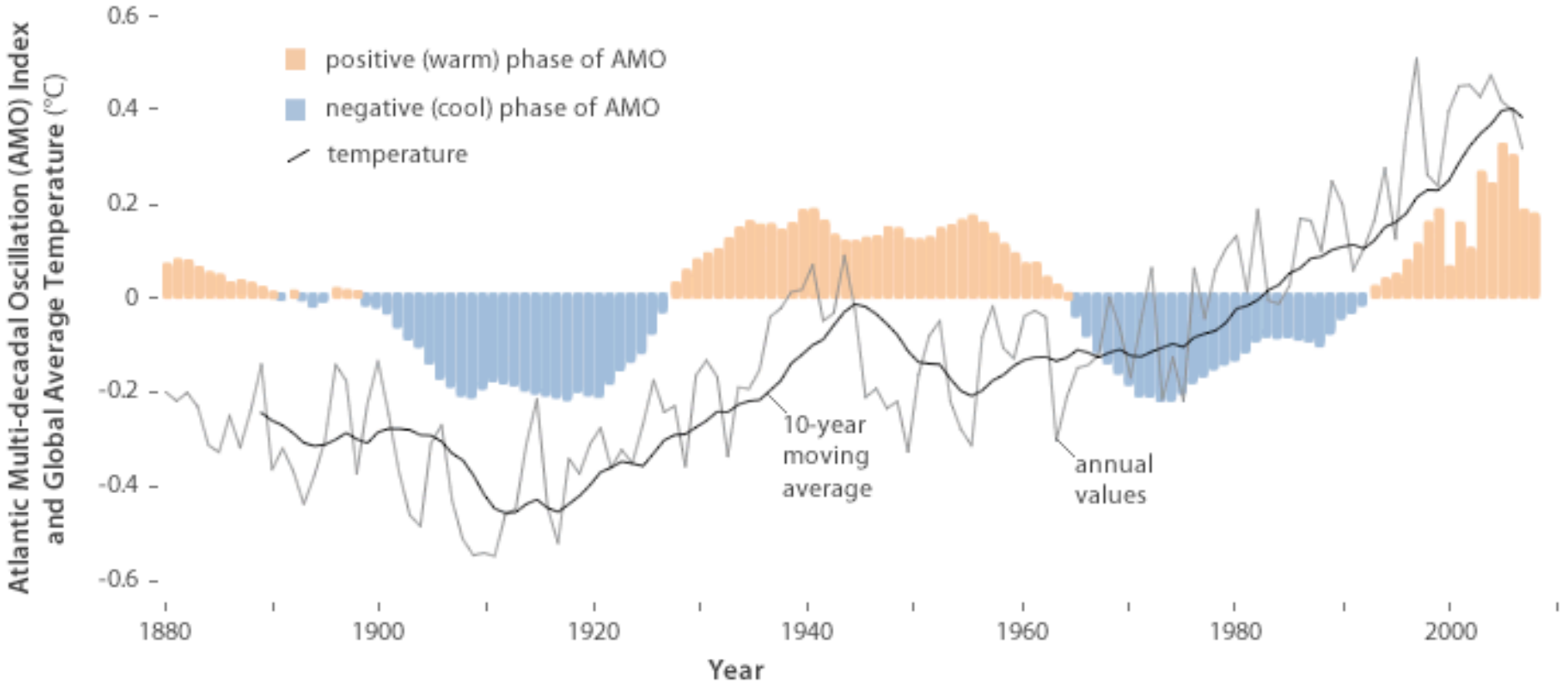


http://www.responsiblebusiness.eu/display/rebwp2/Resilience+thinking



Stabeno et al. 2005, after NRC 2003

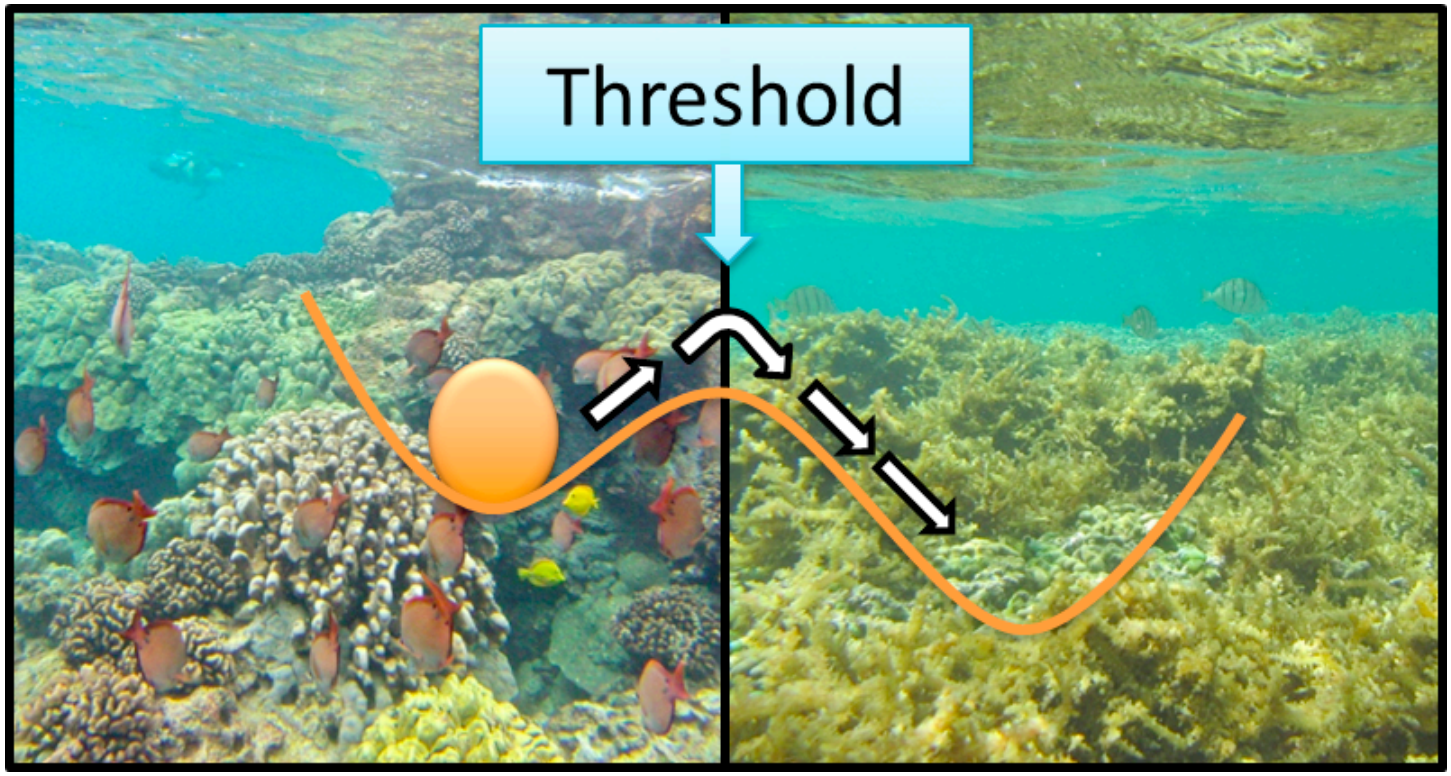
Atlantic Multi-decadal Oscillation



http://www.climatewatch.noaa.gov/

What is a regime shift?

Regime shift: Rapid reorganization of a system from one relatively unchanging state to another. (Carpenter and Folke 2006)



www.oceantippingpoints.org

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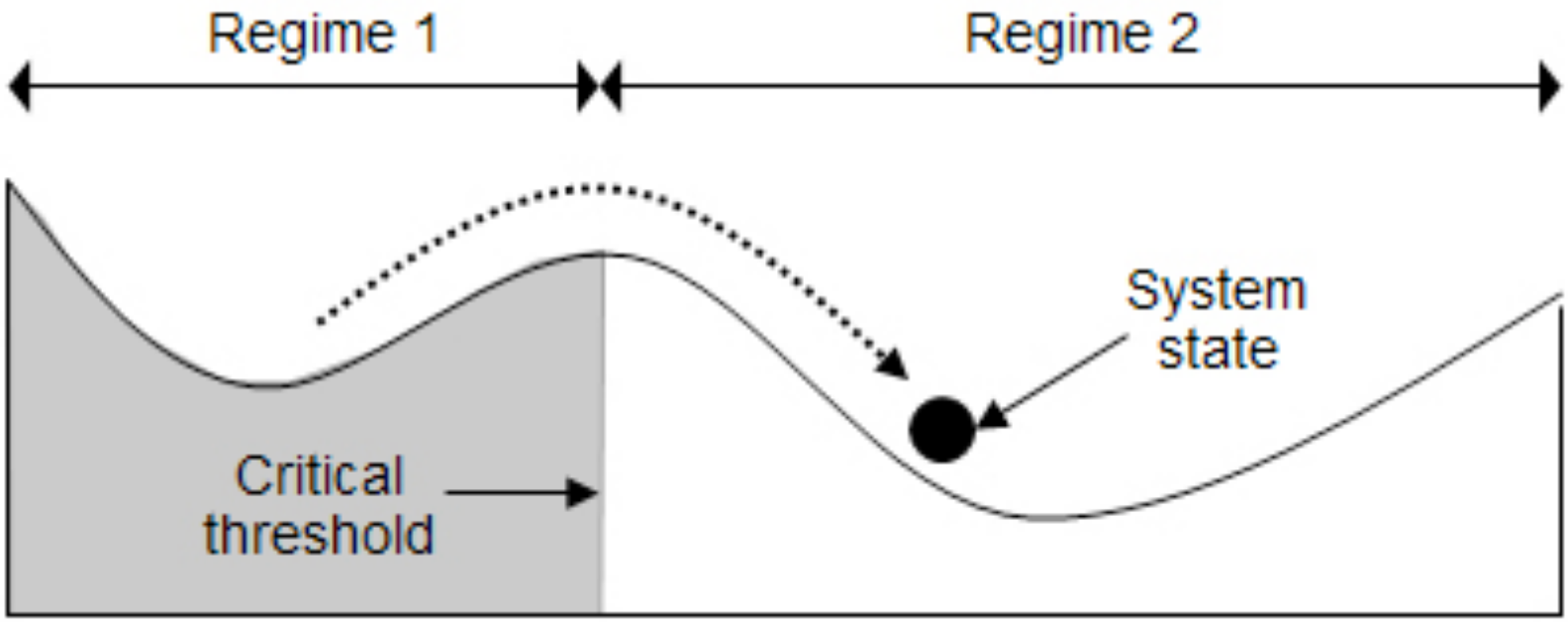
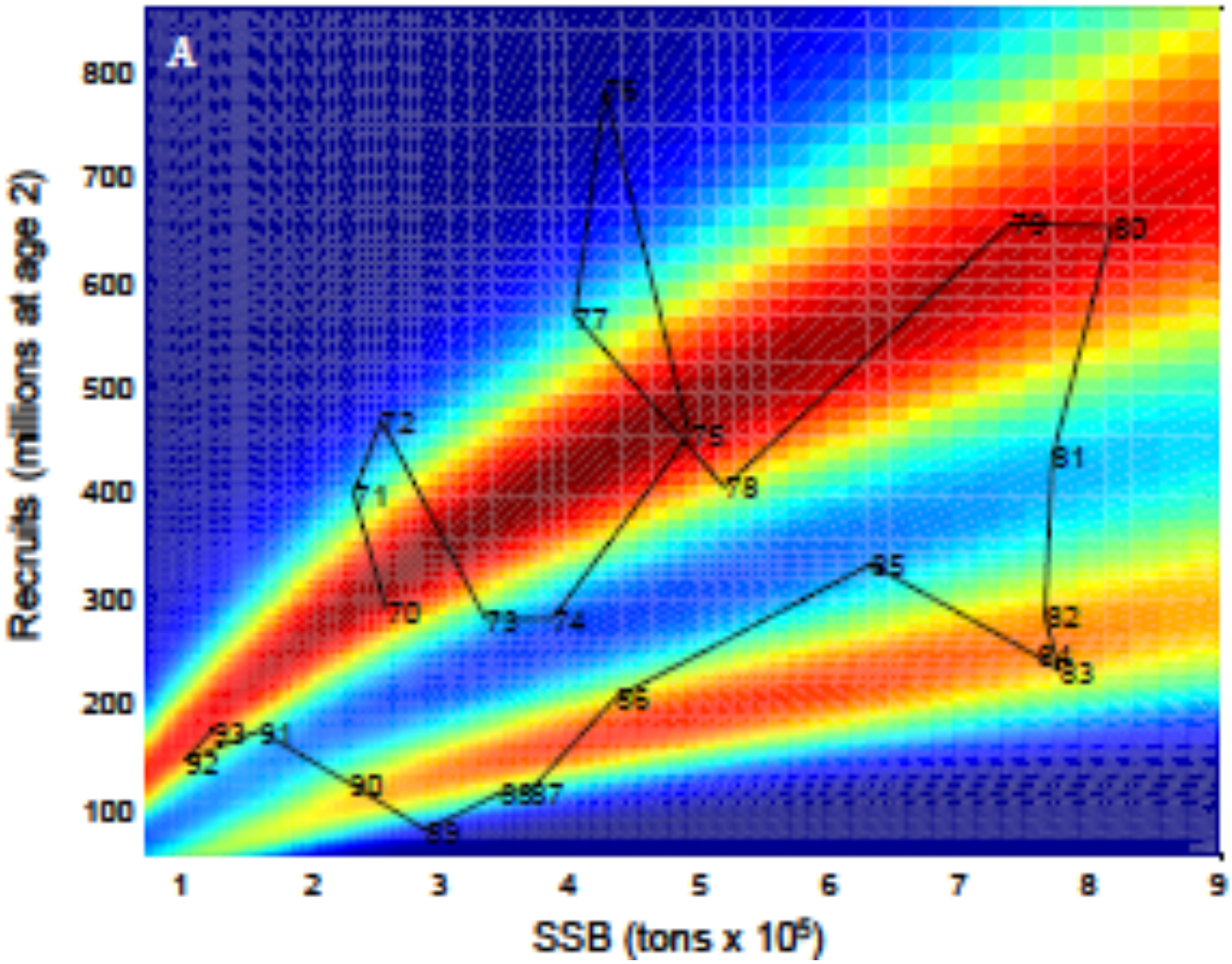


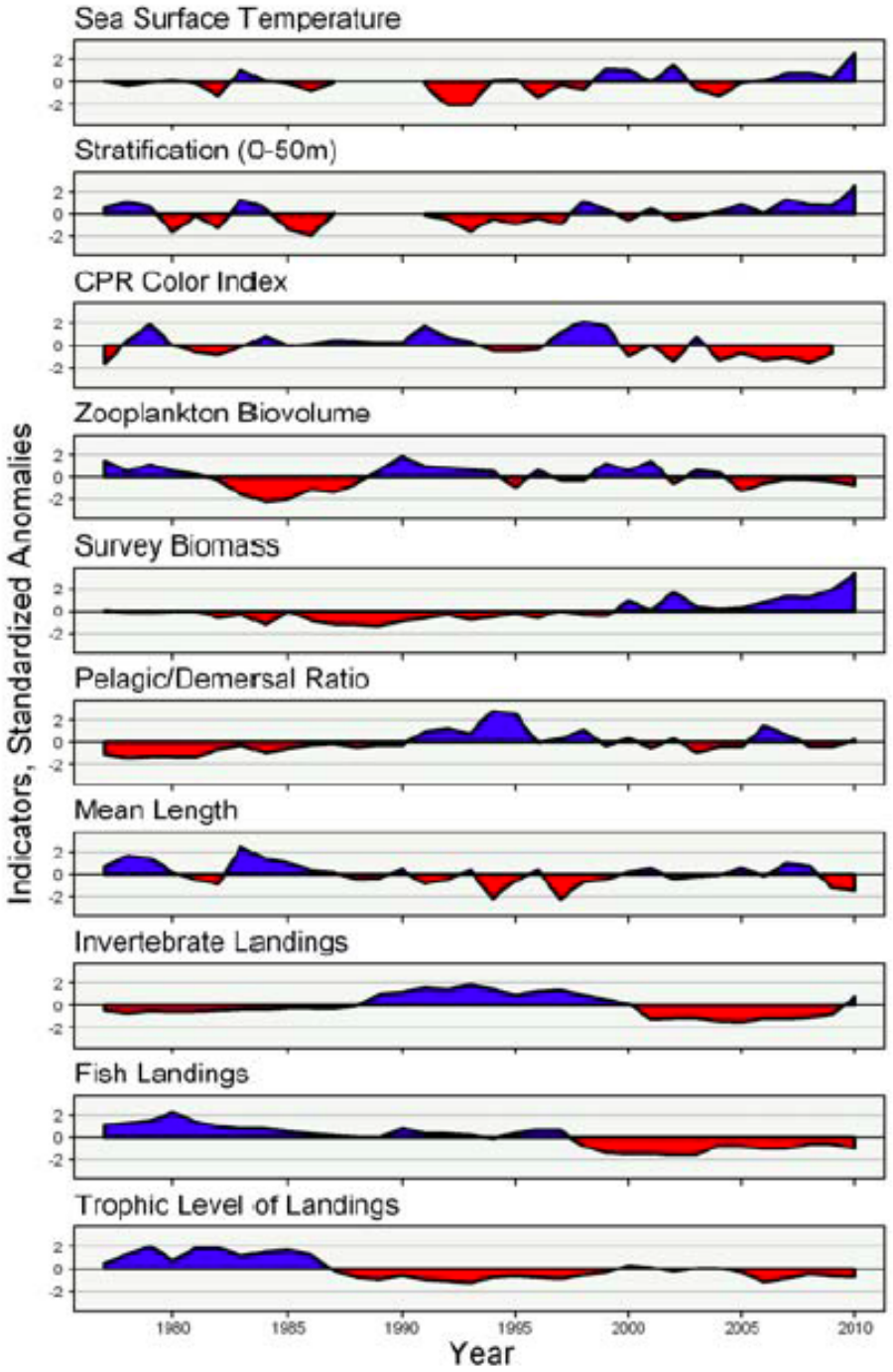
http://www.regimeshifts.org/what-is-a-regime-shift

Pacific Sardine recruitment

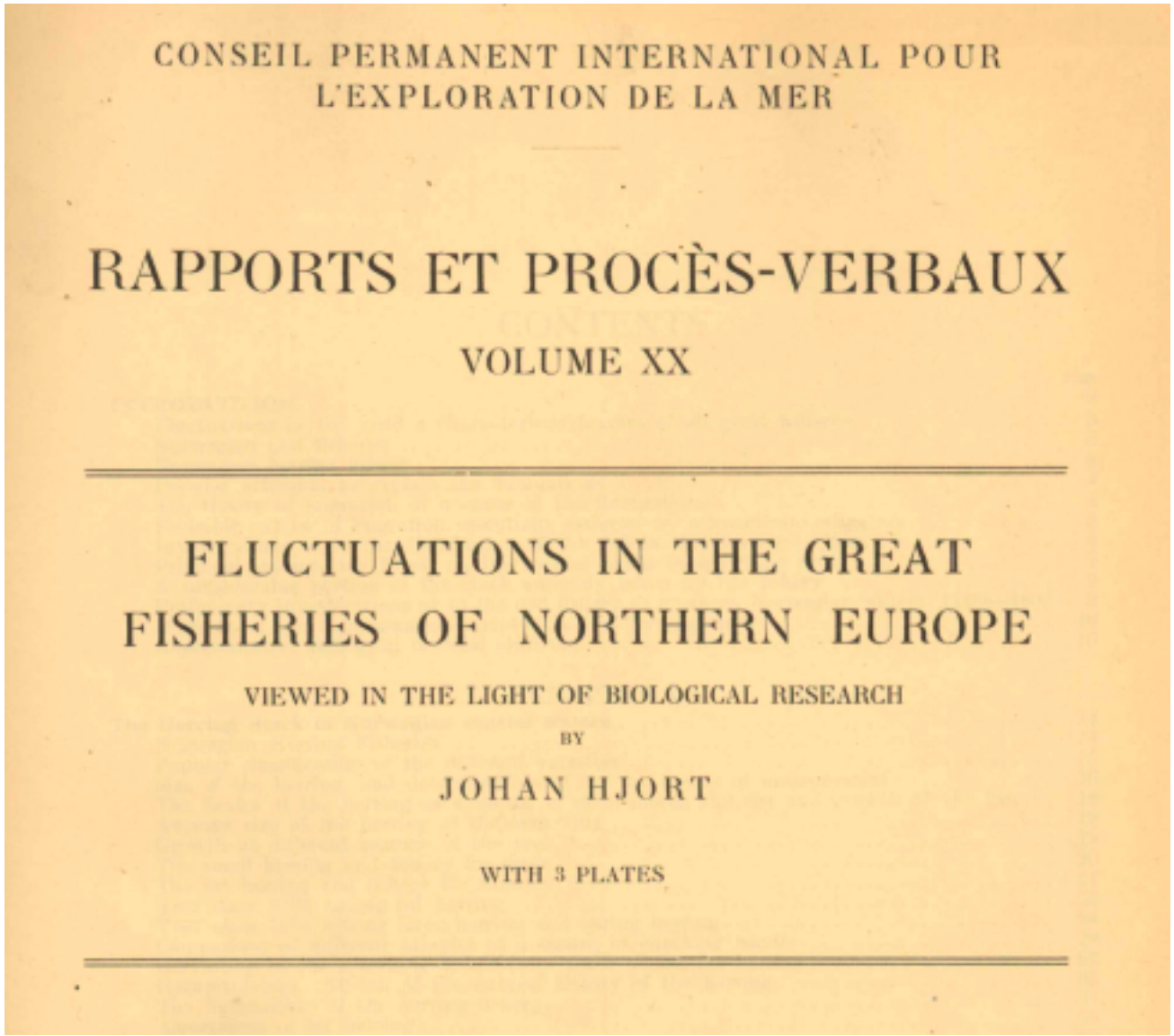


Munch et al. Environmental regimes and density-dependence: a Bayesian modeling approach for identifying recruitment regimes.

Gulf of Maine Ecosystem indicators



Productivity shifts in marine fish



CONSEIL PERMANENT INTERNATIONAL POUR
L'EXPLORATION DE LA MER

RAPPORTS ET PROCÈS-VERBAUX

VOLUME XX

FLUCTUATIONS IN THE GREAT
FISHERIES OF NORTHERN EUROPE

VIEWED IN THE LIGHT OF BIOLOGICAL RESEARCH

BY

JOHAN HJORT

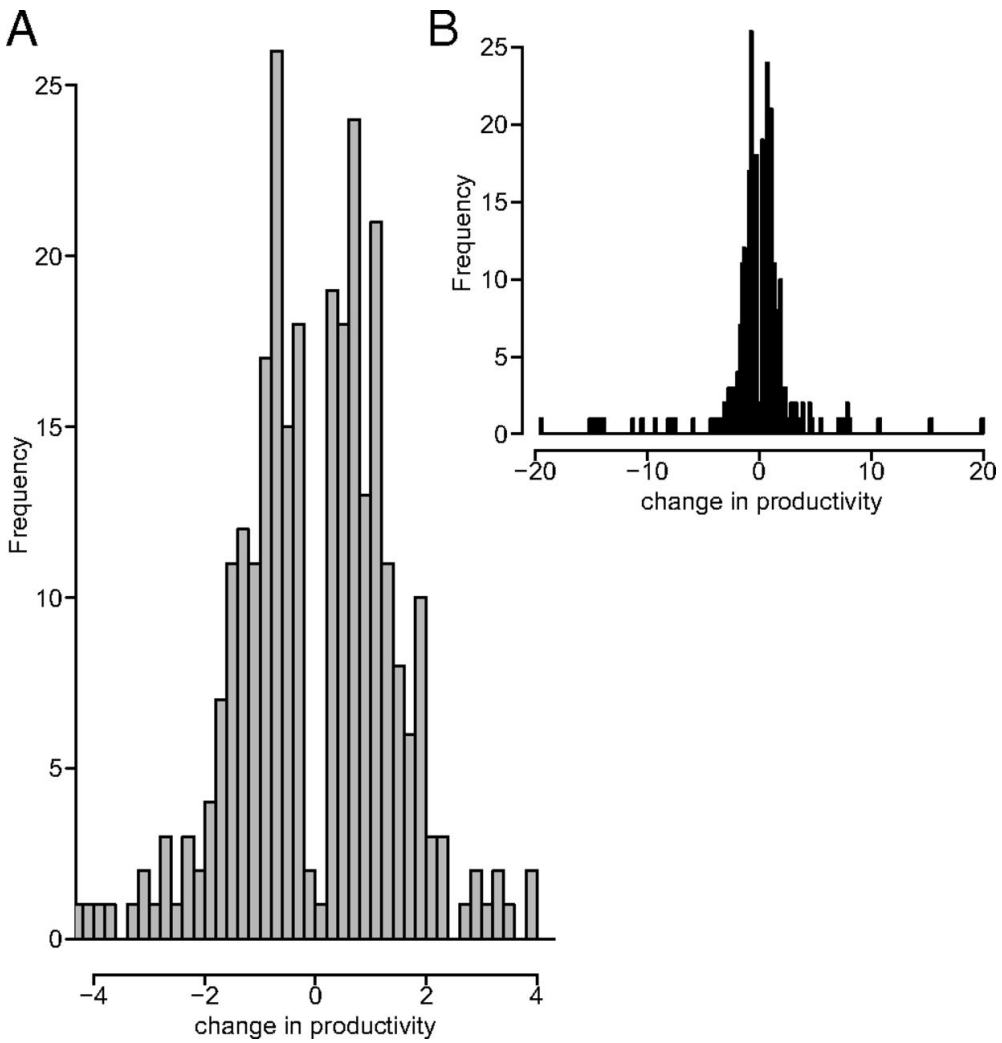
WITH 3 PLATES

Hjort 1914

Productivity shifts in marine fish

Common

High in magnitude



Vert-pre K A et al. PNAS 2013;110:1779-1784

Including regime Shifts in fisheries management

Less ubiquitous

Changes in productivity associated with regimes

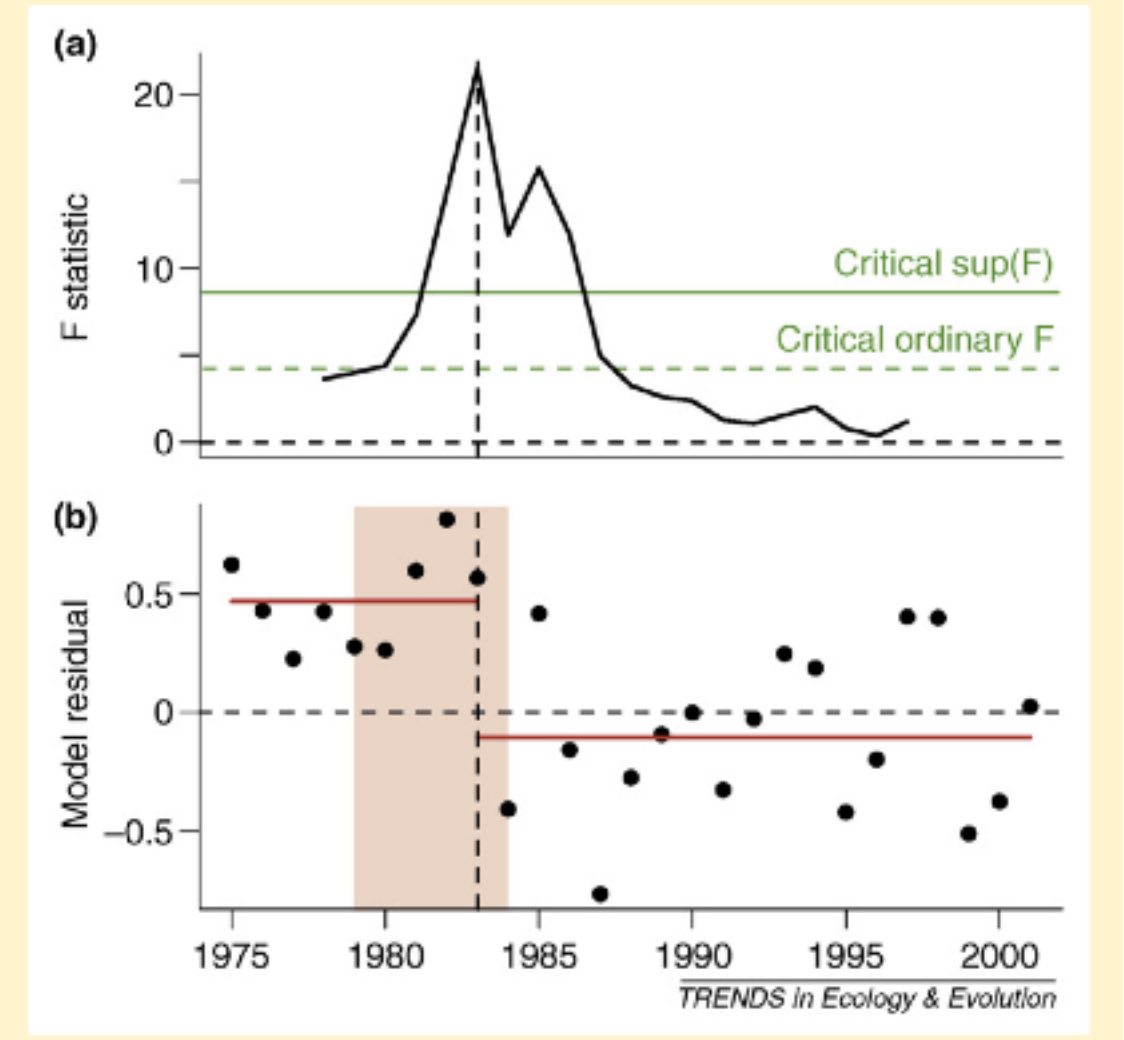
Challenges for management:

(a) how to allocate regime membership for forecast years,

(b) whether to specify regime-driven changes in biological reference points, and

(c) how to determine catch advice for forecast years.

Change-point analysis to identify regime shifts



Ecological thresholds and regime shifts: approaches to identification

Tom Andersen[1], Jacob Carstensen[2], Emilio Hernández-García[3] and Carlos M. Duarte[4]

Trends in Ecology and Evolution Vol.24 No.1

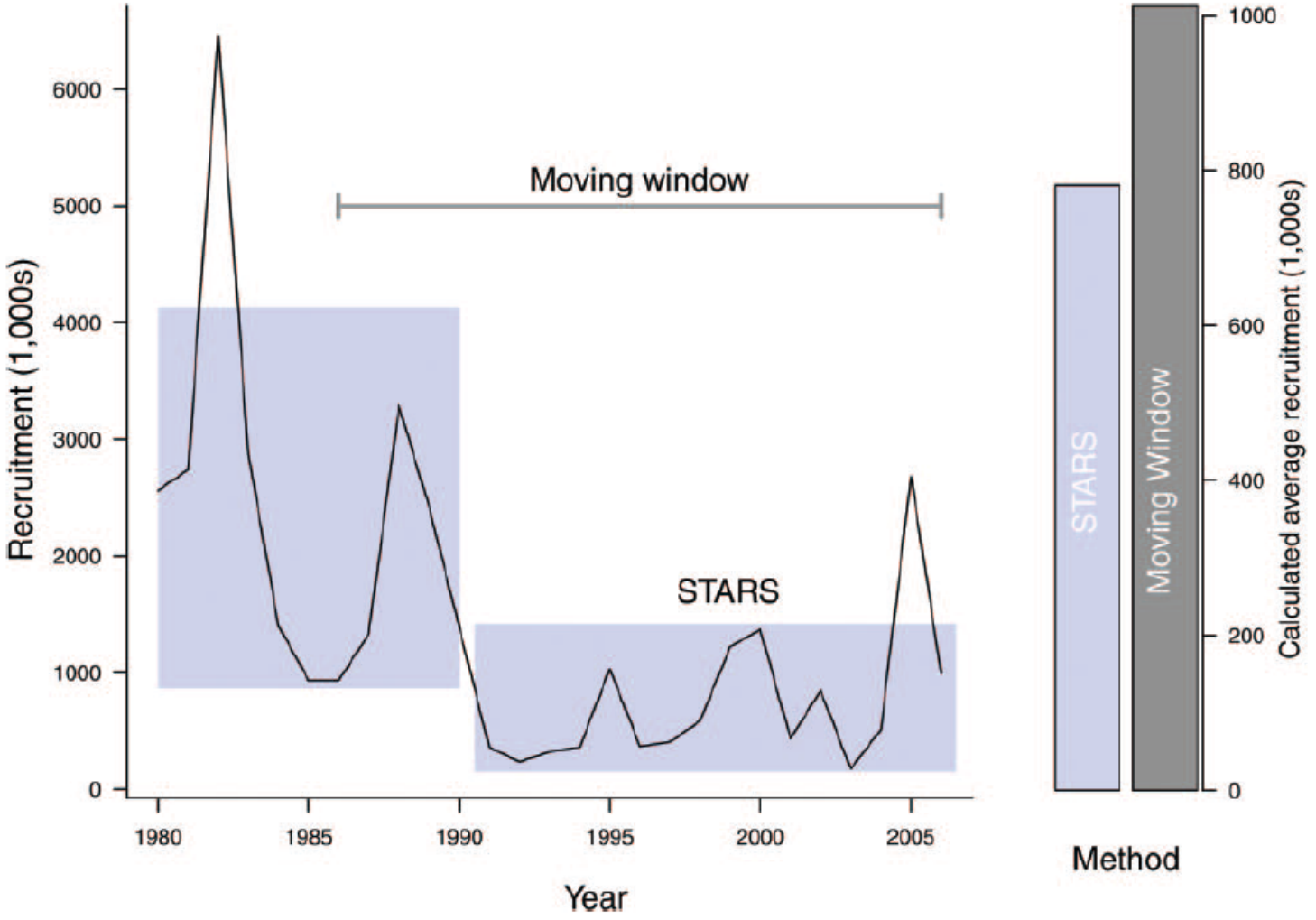
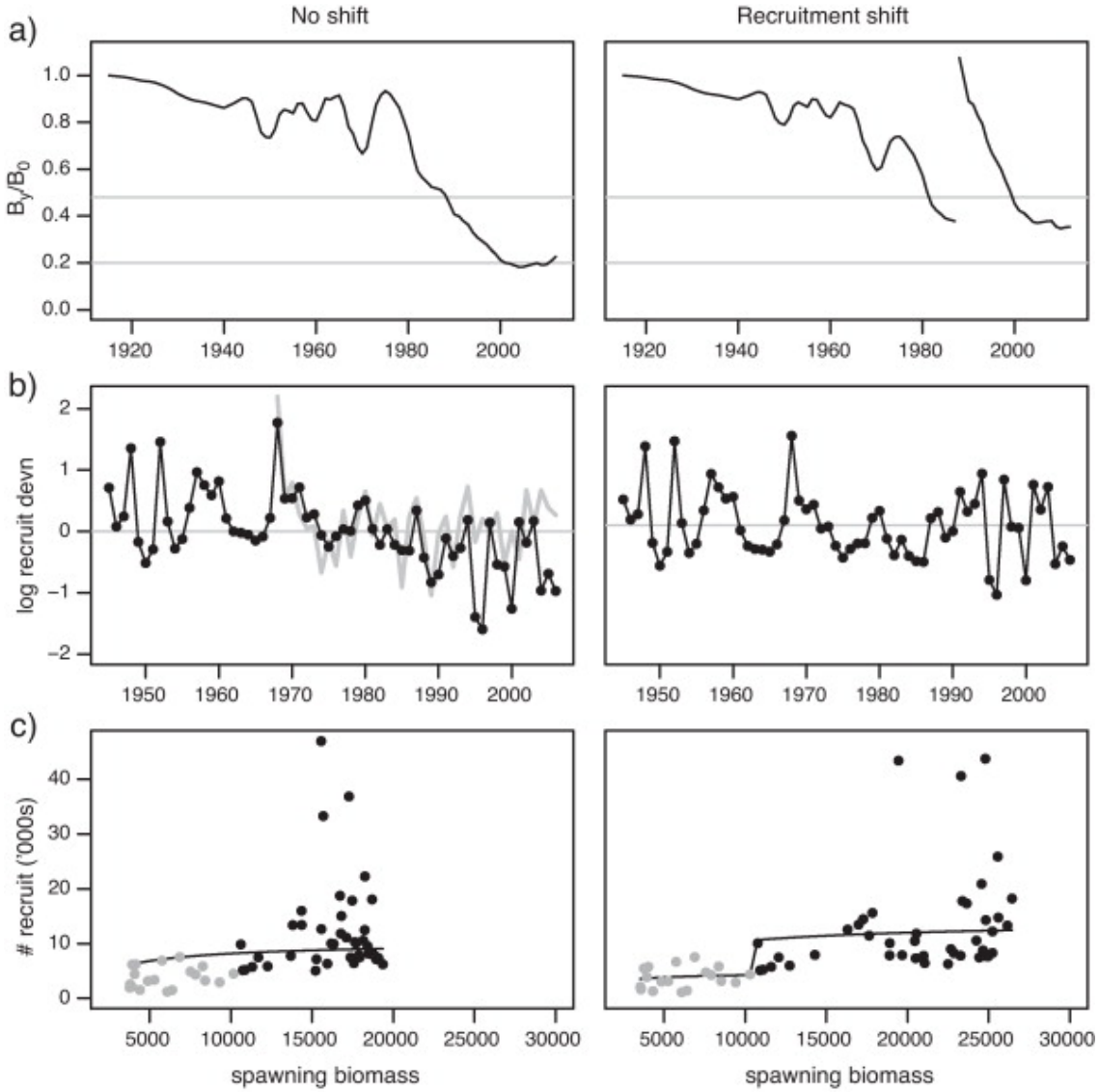


Figure 2. Application of the moving window and STARS approaches for calculating the mean recruitment. The moving window approach in this example always sets the mean recruitment using the most recent 20 years of recruitment estimates, whereas the STARS approach would set the mean recruitment to the mean of the most recent shaded set of recruitments or a new block of recruitments if a new recruitment regime is detected. Note that the recruitments and the average recruitments are on different scales.

Punt et al. 2013



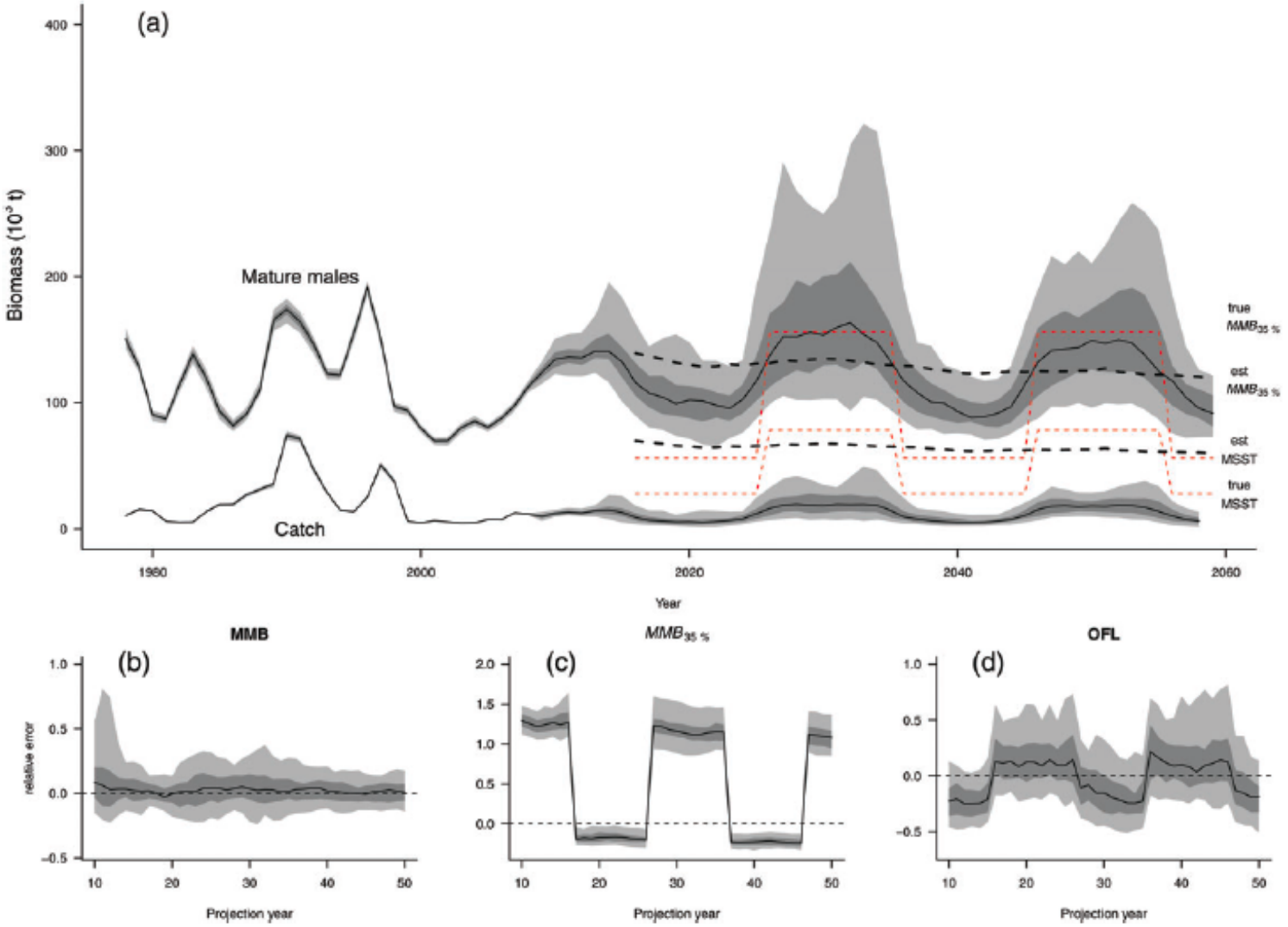
Sally E. Wayte

Management implications of including a climate-induced recruitment shift in the stock assessment for jackass morwong (*Nemadactylus macropterus*) in south-eastern Australia

Fisheries Research, Volume 142, 2013, 47 - 55

http://dx.doi.org/10.1016/j.fishres.2012.07.009

Bering Sea snow crab: evaluating regime-based control rules



Szuwalski, C., and Punt A. E. 2013. Fisheries management for regime-based ecosystems: a management strategy evaluation for the snow crab fishery in the eastern Bering Sea. – ICES Journal of Marine Science, 70: 955–967.

Some thoughts ….

- Regime determination often post-analysis (not part of estimation)
- Management advice determined based on whether to accept one regime or not.
  (i.e. you know which regime you will be in).
- Unless the control rule includes regime allocation, when do you make a decision to adopt the new regime?
- Does your policy allow for going back?

More thoughts….

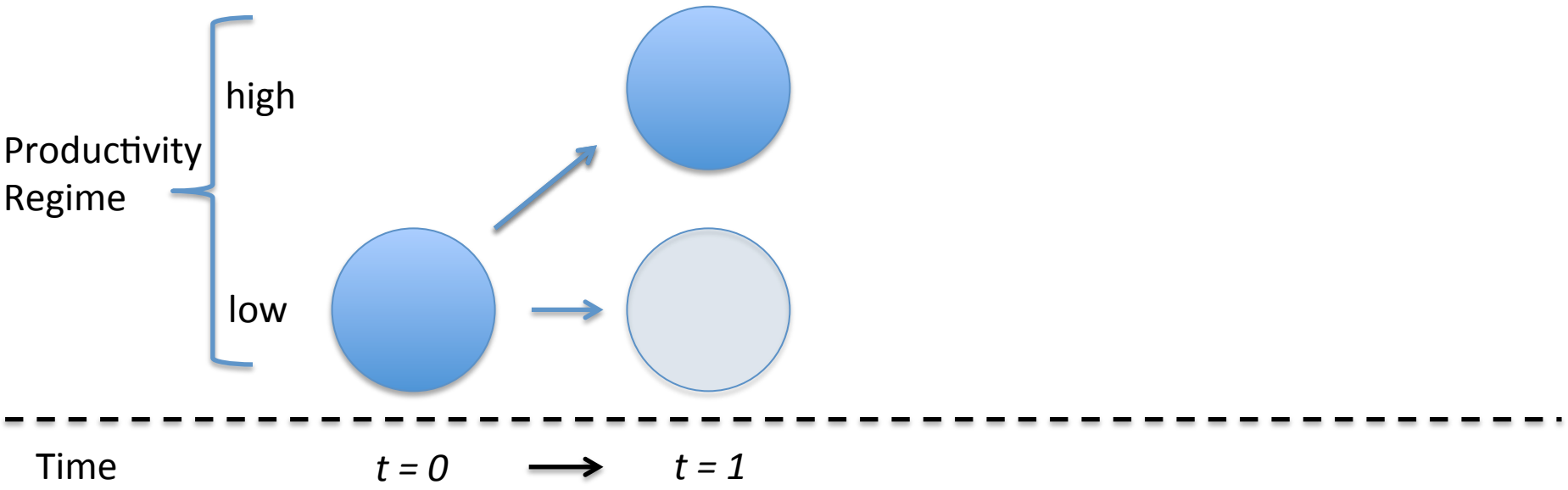
- Can we account for uncertainty in regime membership for advice years?
- Do state-transition models such as Markov switching models (or Hidden Markov models) offer a solution?
- Assume regime dynamics evolve over time according to Markov chain.
  - estimate probabilities for transition among regimes,
  - productivity parameters associated with each regime,
  - estimate probabilities for regime membership for the terminal year, determine catch advice.

Markov switching models (HMMs)

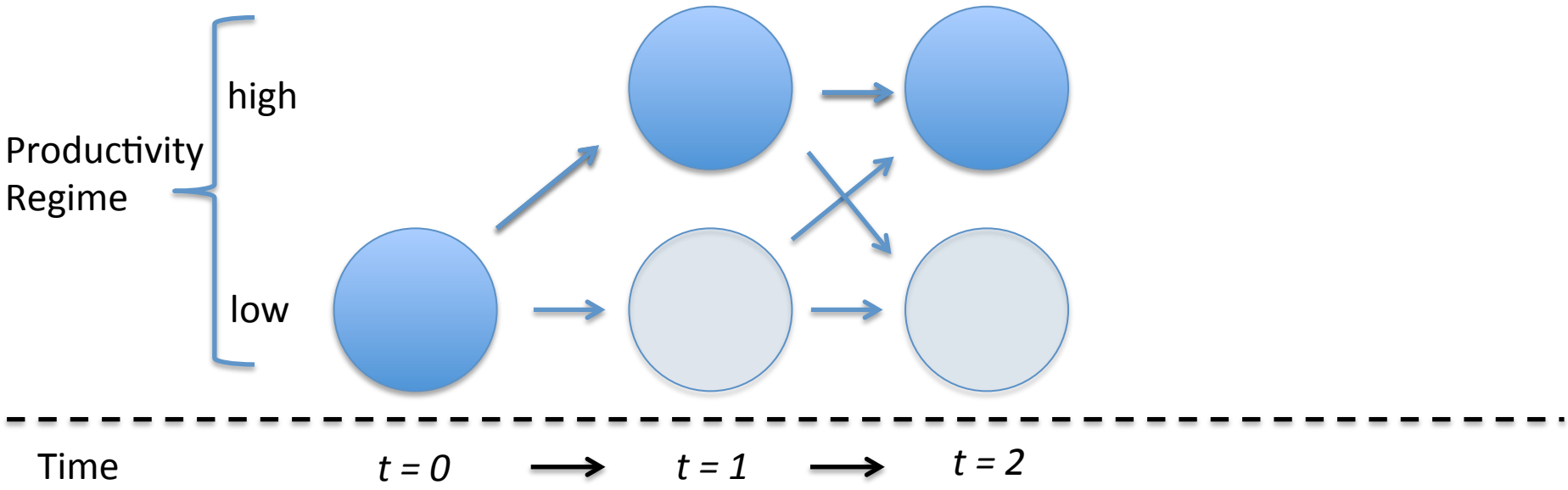
- Developed for speech recognition, used in finance and econometrics.
- Application in ecology largely associated with movement and behavioral modeling
- Same dependence structure as state-space models.

Hidden Markov Modeling

Hidden Markov Modeling



Hidden Markov Modeling



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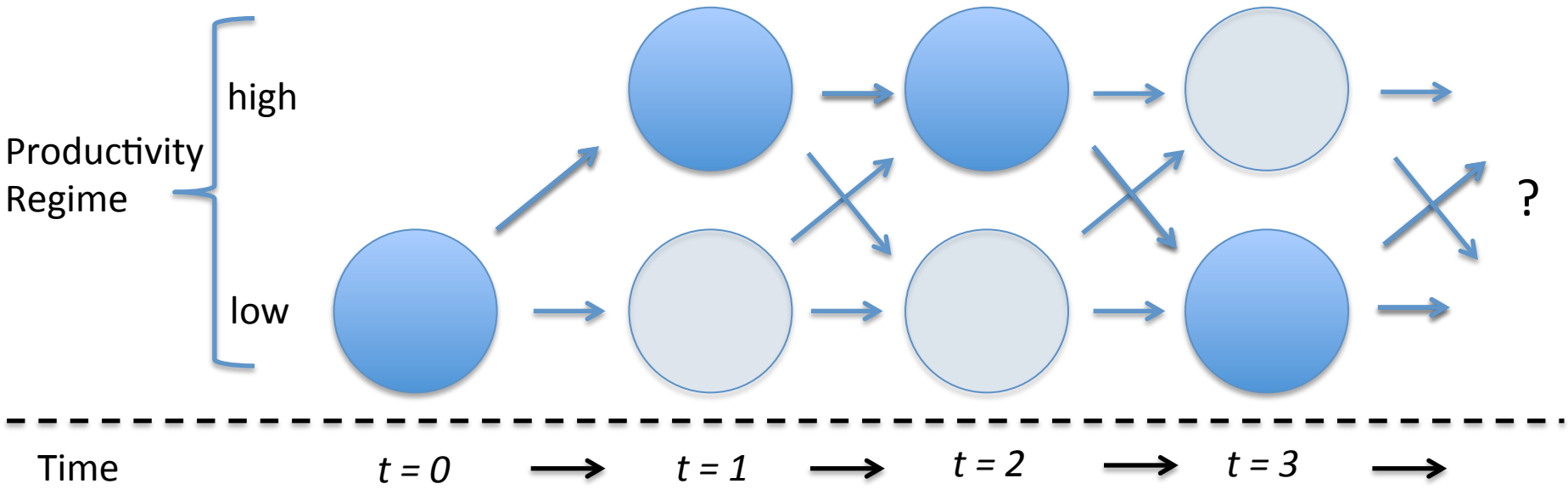

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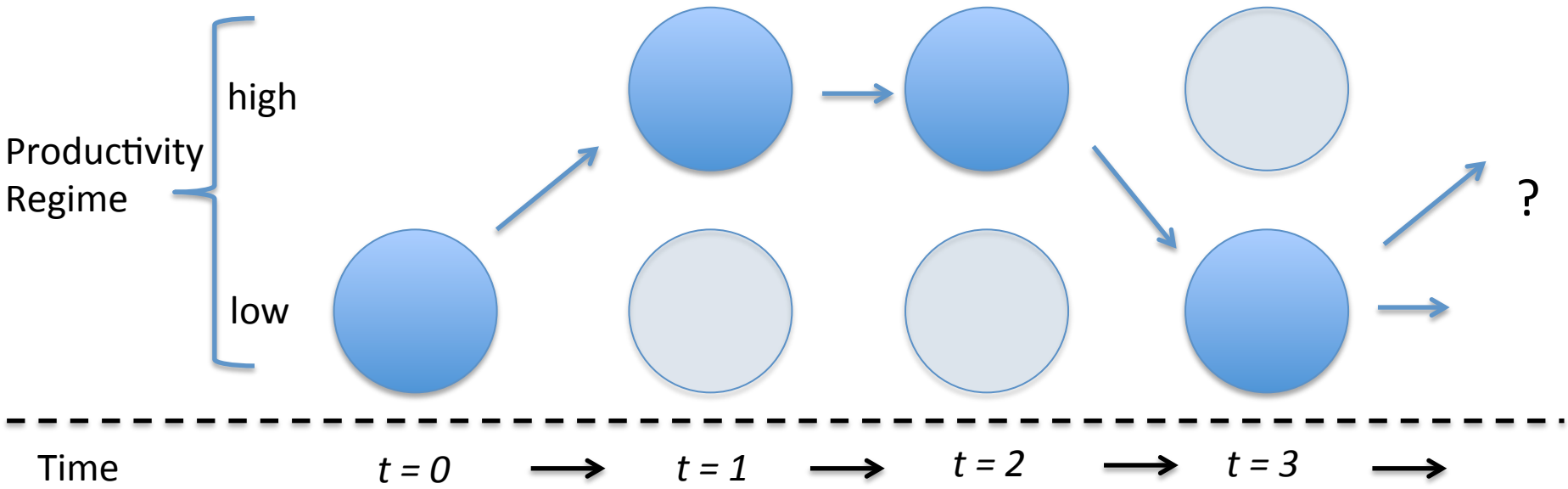

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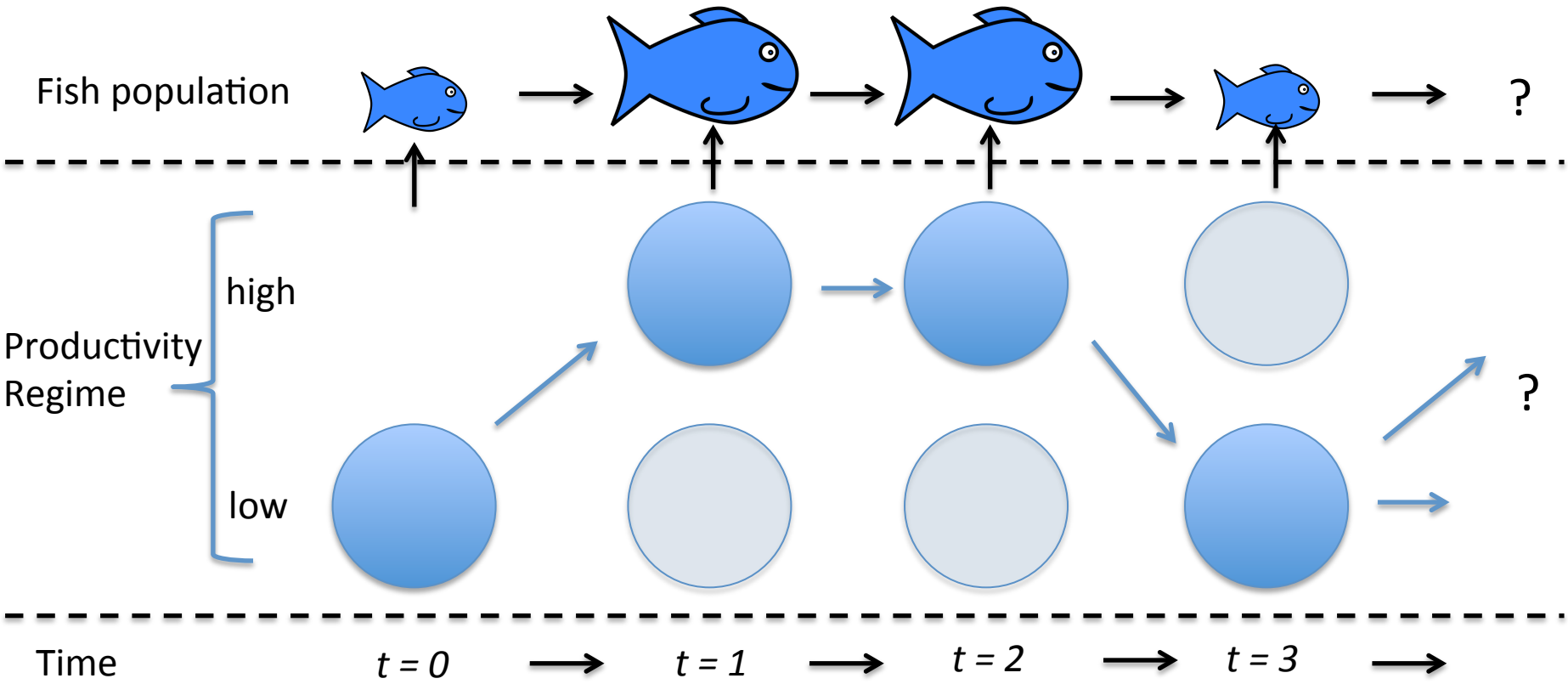

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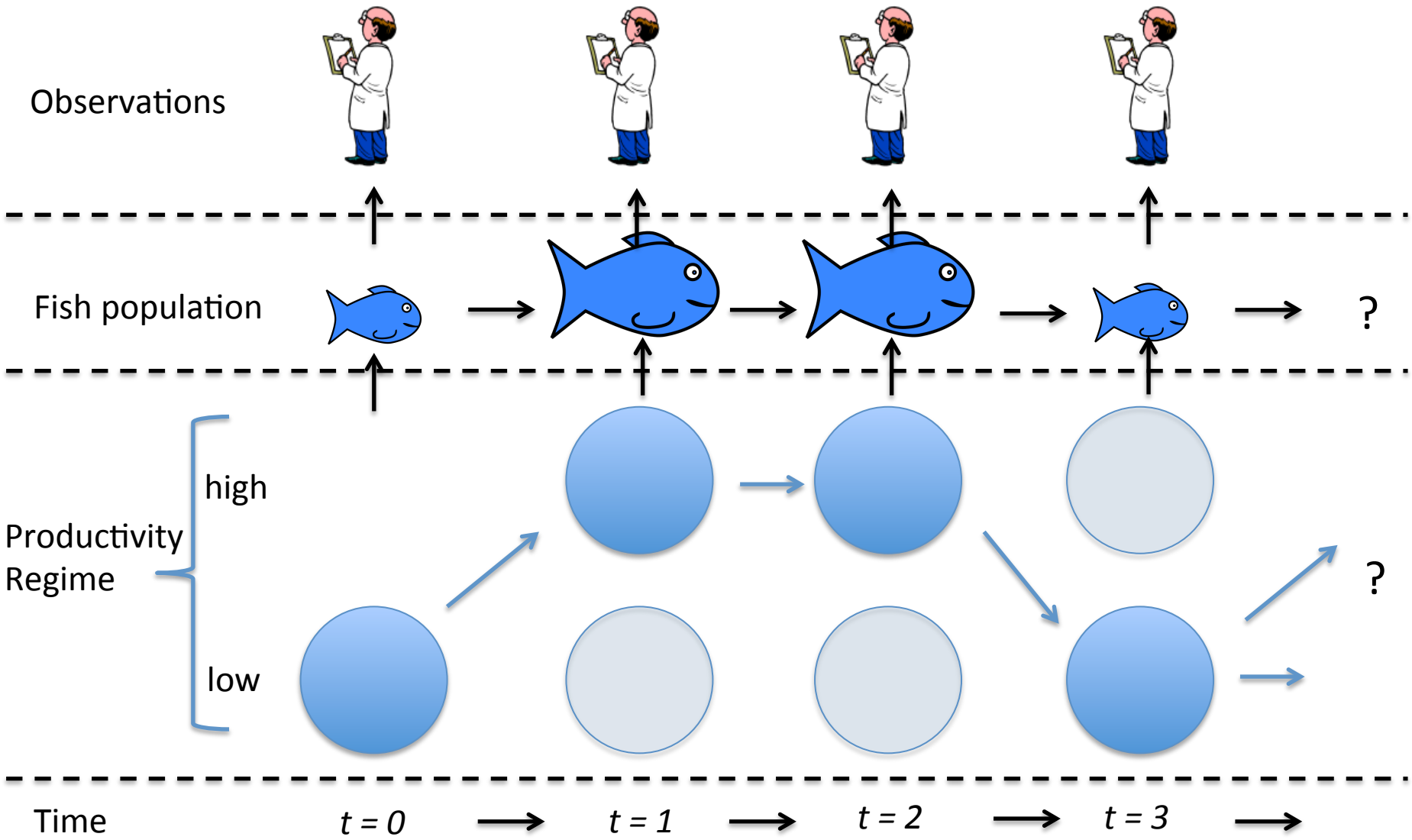

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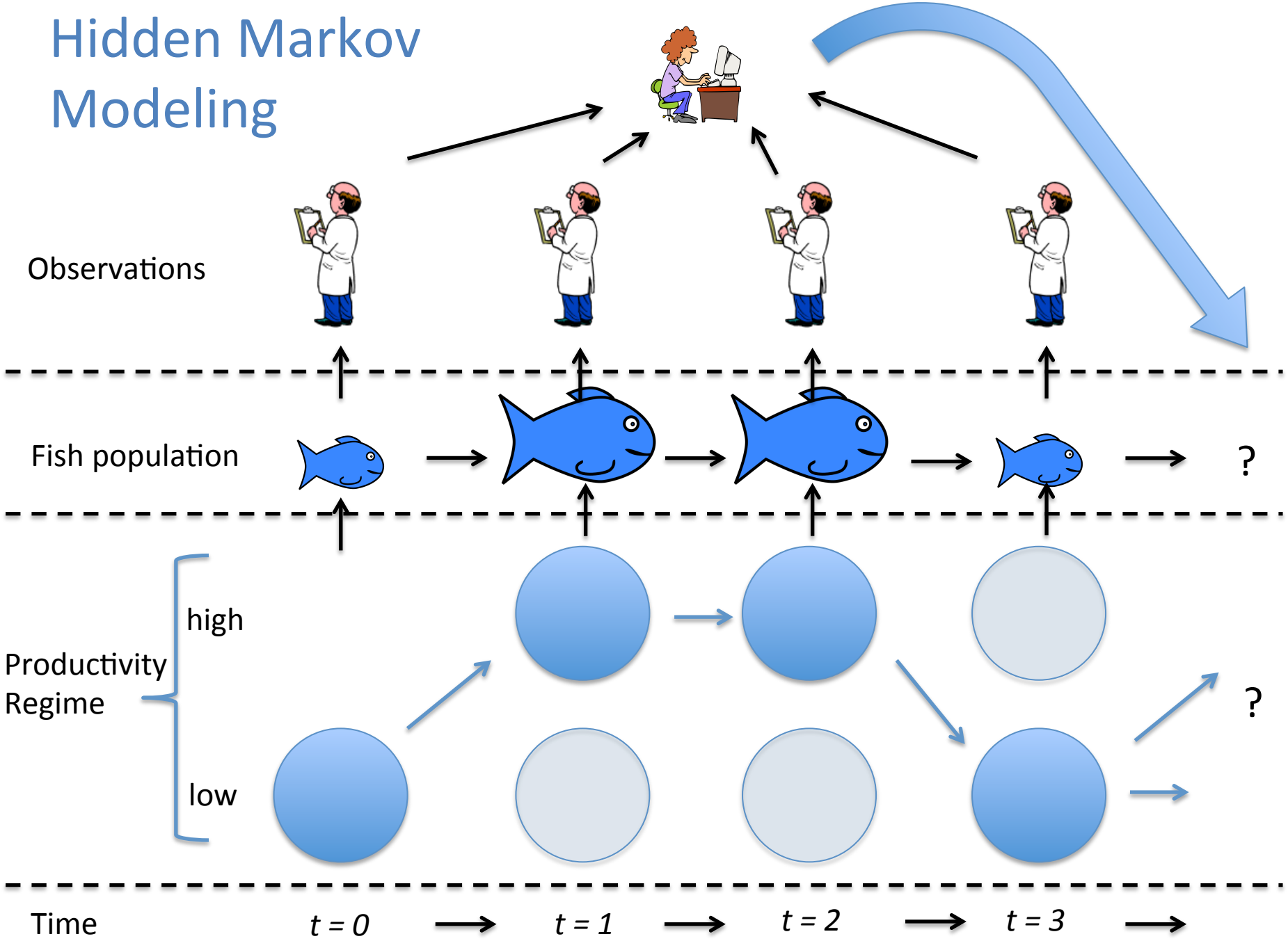

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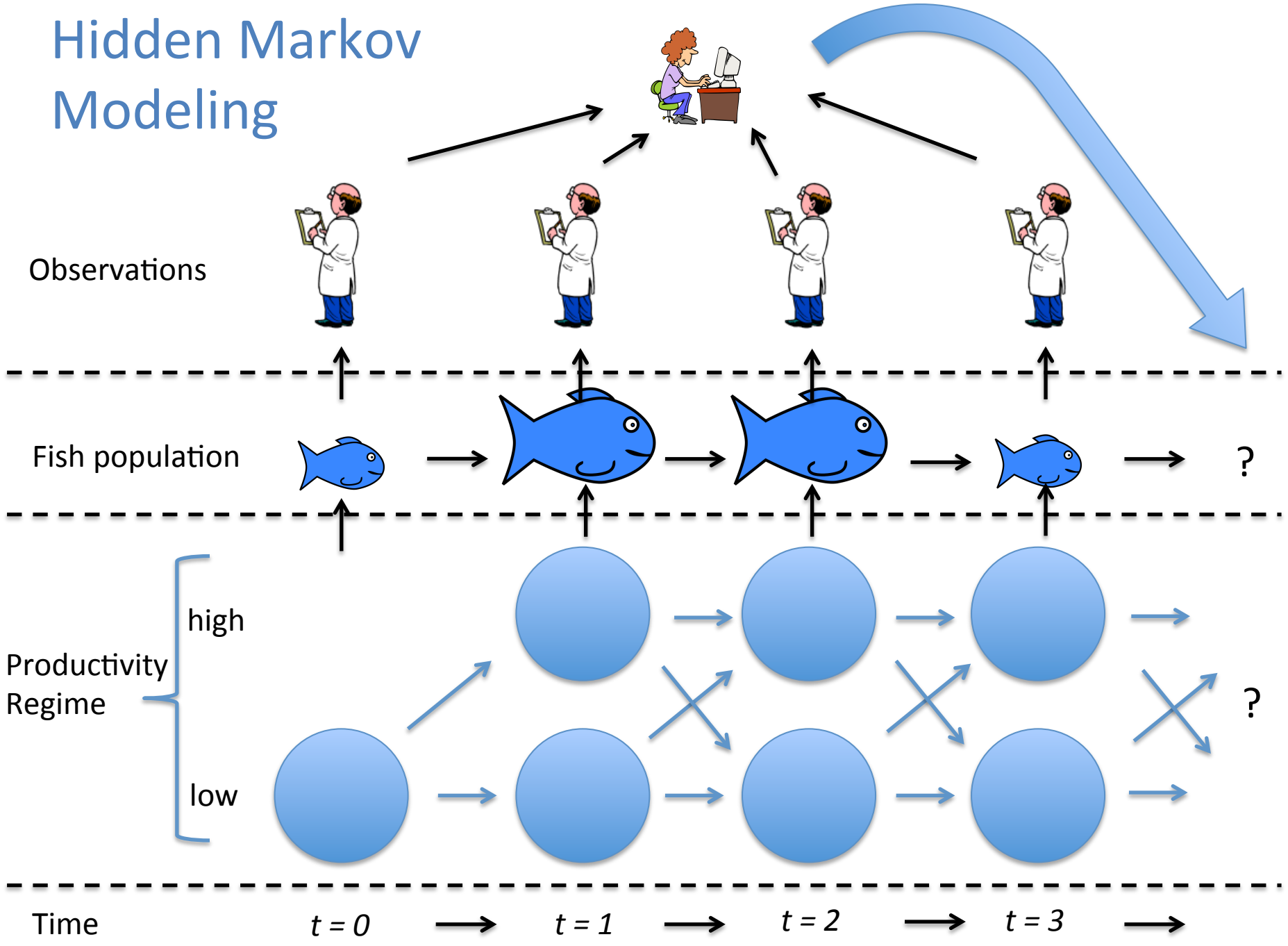
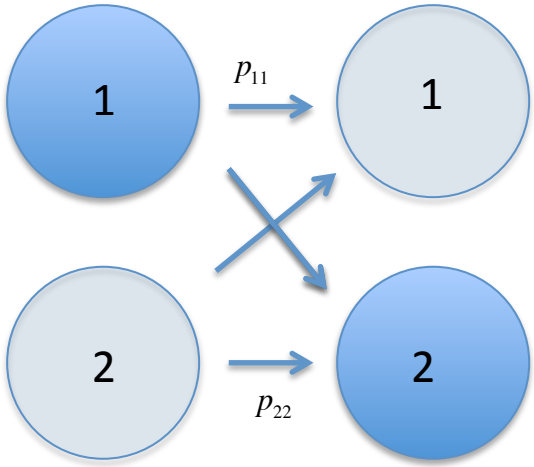


Estimate probability of regime membership over time

State at *t+*1 dependent on state at time *t* and the transition probabilities



$$\Gamma = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix}$$

where $p_{12} = 1 - p_{11}$

$$P(\text{Regime}_{t+1} = 1) = \frac{\sum_{m=1}^{M} P(\text{Regime}_t = m)\Gamma(m \to 1)}{\sum_{m=1}^{M}\sum_{n=1}^{N} P(\text{Regime}_t = m)\Gamma(m \to n)}$$

Management advice

- Project Markov chain for an additional year
- Calculate posterior distribution for u_{MSY} given probabilities of membership in each regime.
- Apply to model biomass estimate to obtain next year's catch under the regime-dependent MSY exploitation rate.

Application: biomass dynamic model with regime switching in population growth rate

- Assume intrinsic growth rate follows regimes

$$B_{y+1} = \left(B_y + r_y(1 - B_y / K) - C_y\right)e^{\varepsilon_y}$$

$$r_y = \tilde{r}(\text{Regime}_y)$$

$$\text{Regime}_y \sim dcat(\,\Gamma[,\text{Regime}_{y-1}])$$

$$I_y = qB_y e^{\eta_y}$$

- Additional parameters: extra *r's*, transition probabilities, regime state distribution in initial year.

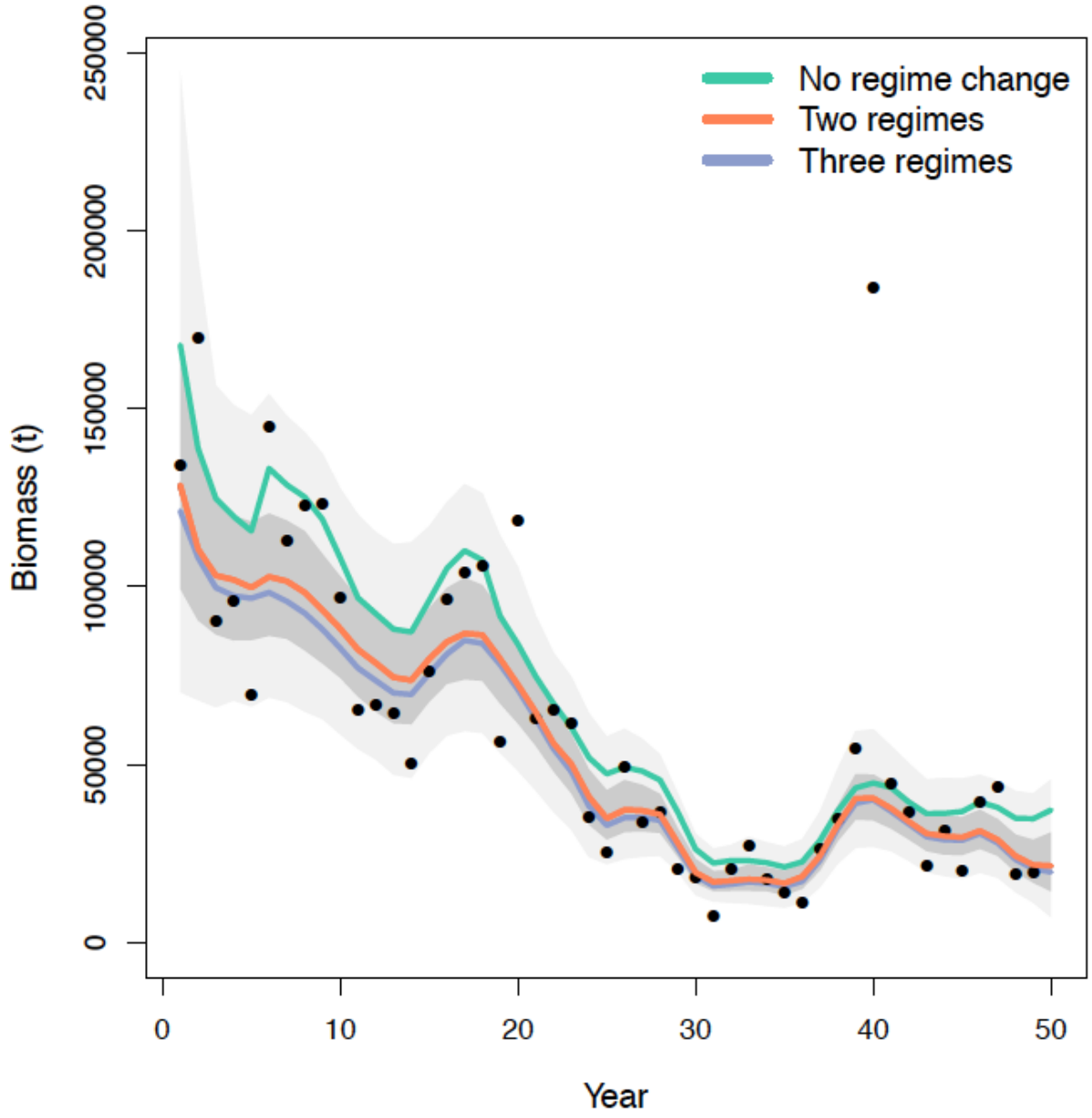
Application: New England groundfish

- Models fit using JAGs

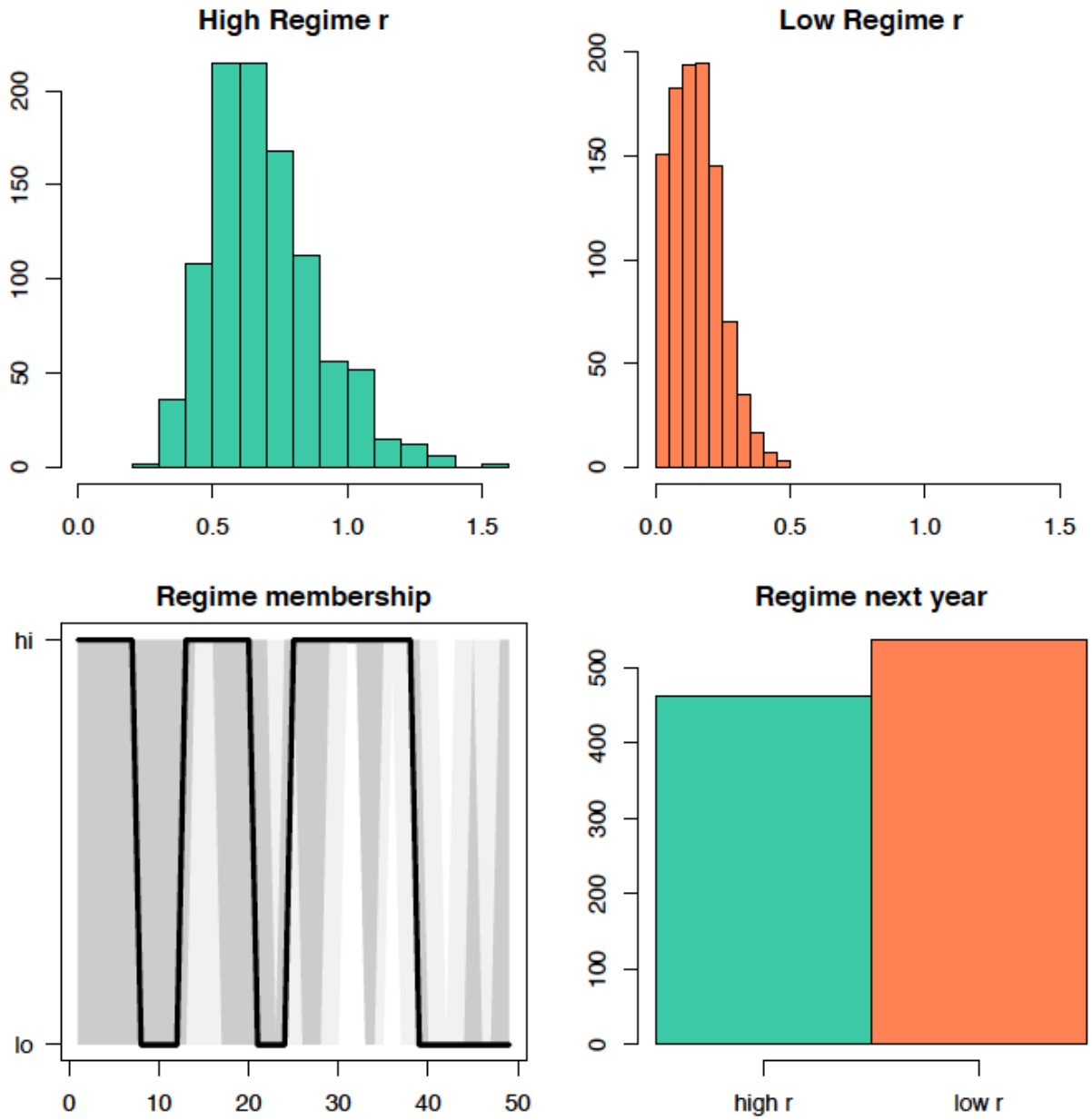
- Fit to fall survey biomass data (1963-) and catches
  (totals from most recent assessment docs)

- Fit models with no regimes, and 2 or three regimes.

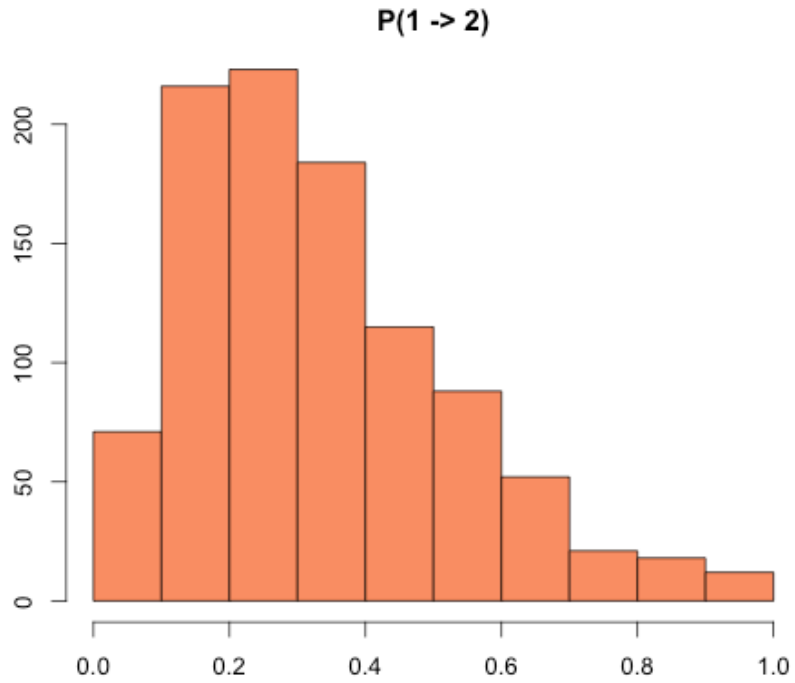
Gulf of Maine cod: fit to fall biomass survey

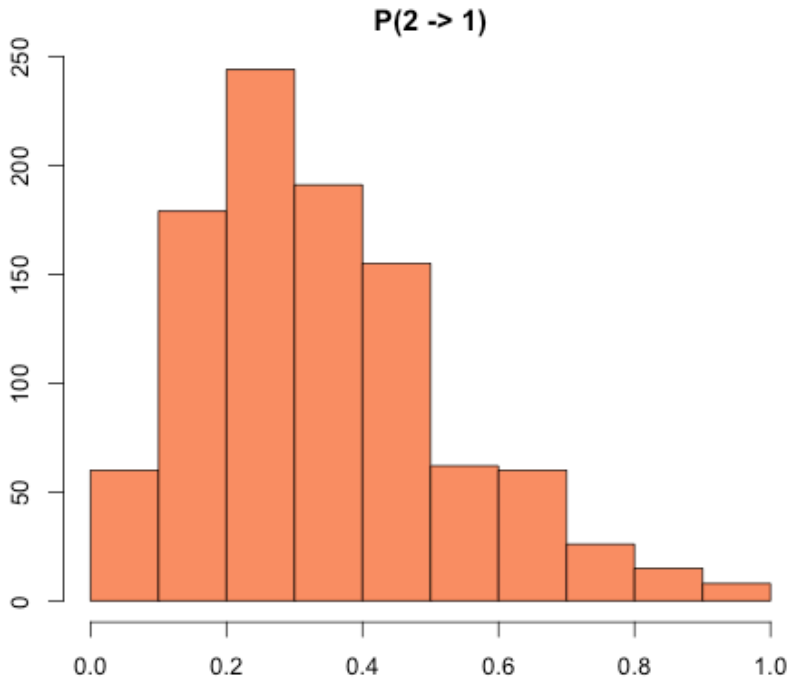


Gulf of Maine cod: Two regimes



Regime transition probabilities
Gulf of Maine cod





Model selection: DIC results

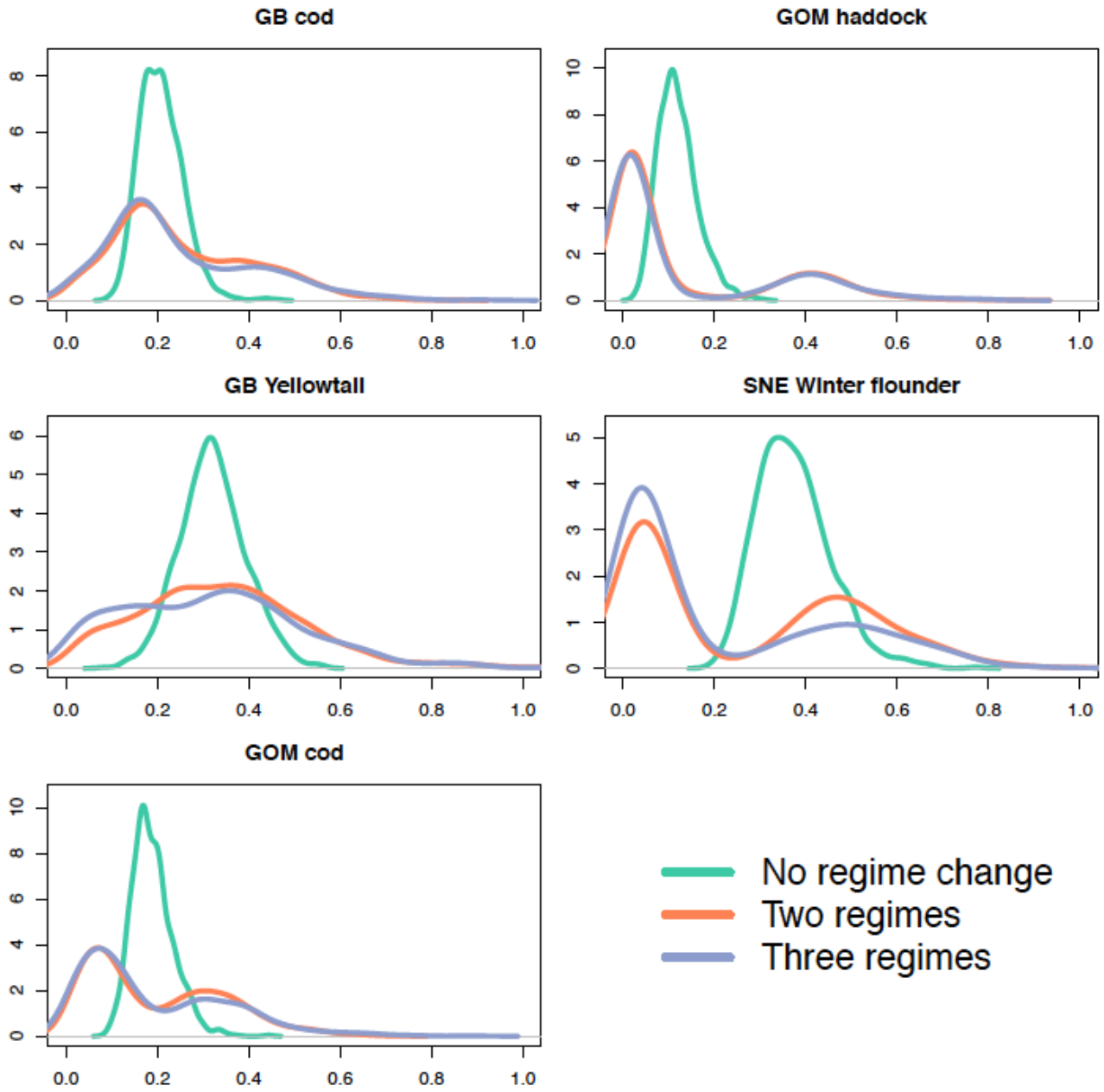
	No regimes	2 regimes	3 regimes
GB cod	259.39	251.50	**250.09**
GOM haddock	**183.43**	189.68	189.17
GB Yellowtail flounder	589.43	587.51	**587.03**
SNE Winter flounder	102.48	**82.65**	82.66
GOM cod	337.75	**224.44**	343.29

DIC references:

1. Gelman, Andrew; Carlin, John B.; Stern, Hal S.; Rubin, Donald B. (2004). *Bayesian Data Analysis: Second Edition*. Texts in Statistical Science. CRC Press. ISBN 1-58488-388-X.

2. Spiegelhalter, David J.; Best, Nicola G.; Carlin, Bradley P.; van der Linde, Angelika (October 2002). "Bayesian measures of model complexity and fit (with discussion)". *Journal of the Royal Statistical Society, Series B* **64** (4): 583–639. doi: 10.1111/1467-9868.00353.

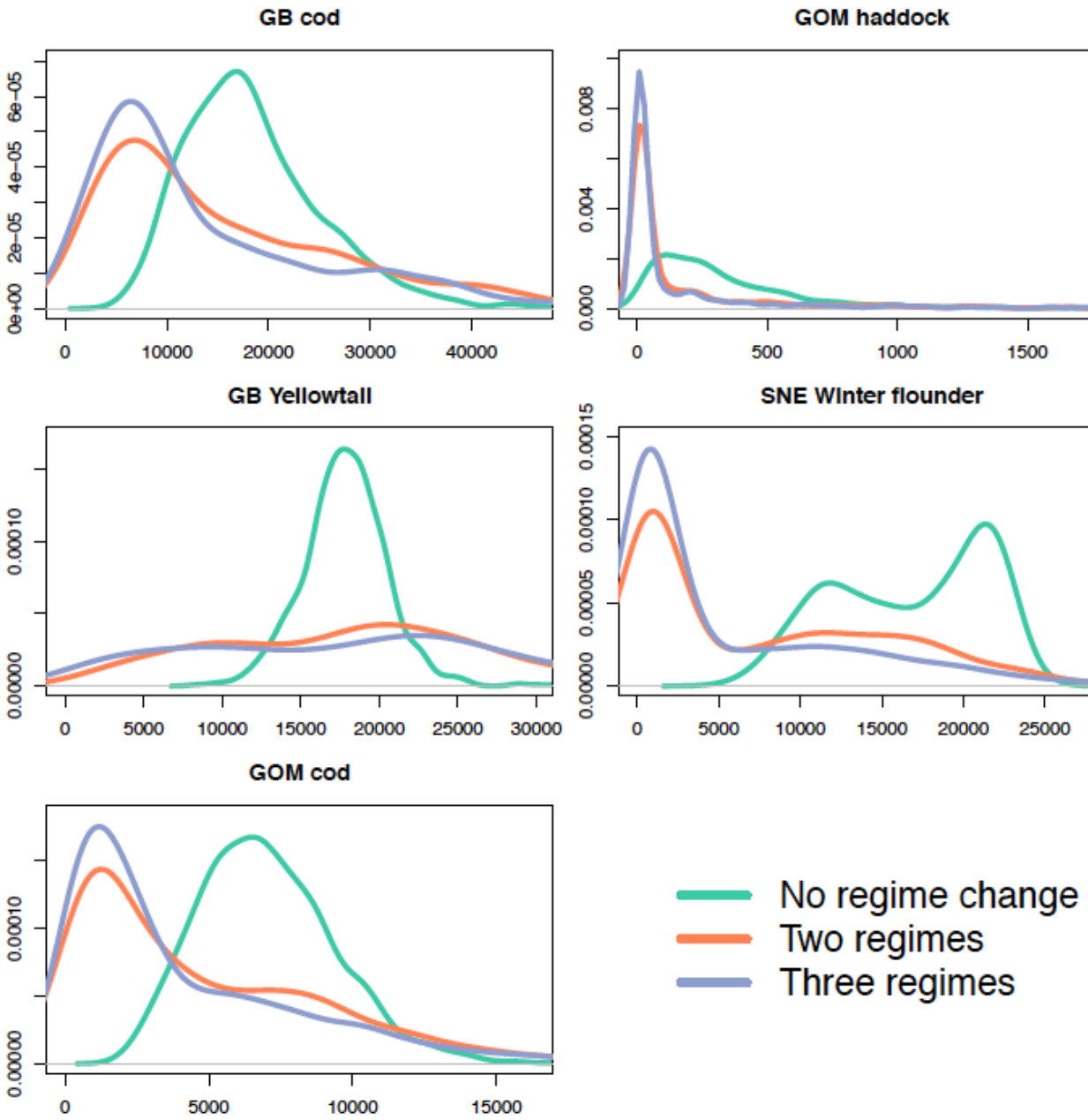
MSY exploitation rate next year



Catch (t) next year under u_{MSY} [posterior median]

	No regimes	2 regimes	3 regimes
GB cod	17,523	11,702	**9,543**
GOM haddock	**248**	22	15
GB Yellowtail flounder	17,799	19,239	**19,639**
SNE Winter flounder	17,568	**3,829**	1,497
GOM cod	6,778	**3,304**	2,478

u_{MSY} catch next year



Results summary

- Models with regime switches better fits in some cases.
- Ability to distinguish among # of regimes challenging.
- Including regimes can substantially change harvest recommendations.

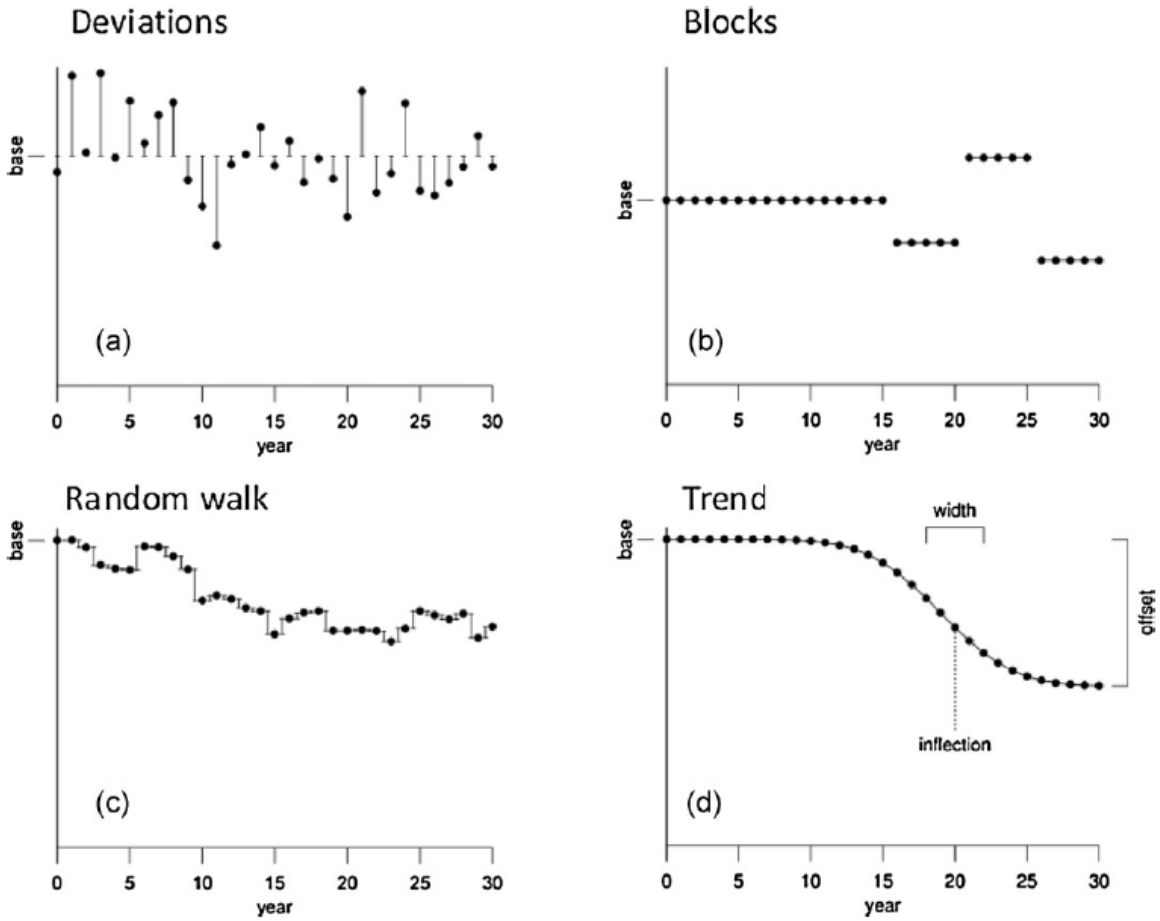
Extensions & Further work

- Include HMM in age-structured models
- Multi-species
- Time-dependent transition probabilities
- Simulation testing
  - What happens when we fit a model with regimes to data generated from a model without regime shifts?
- Compare with alternatives (STARS-based HCRs, dynamic B0), e.g. through MSE

Time-varying parameters in stock assessment

Markov switching just one example to implement time-varying process

R.D. Methot Jr., C.R. Wetzel / Fisheries Research 142 (2013) 86–99



Take Home Messages

- Regime shifts are common, we need to understand how robust our scientific and management tools are to them.
- Markov Switching models provide a pathway for estimating regimes and integrating uncertainty into fisheries policy.
- Harvest policy will differ when based on regime shifts: important to understand consequences of adopting these approaches.

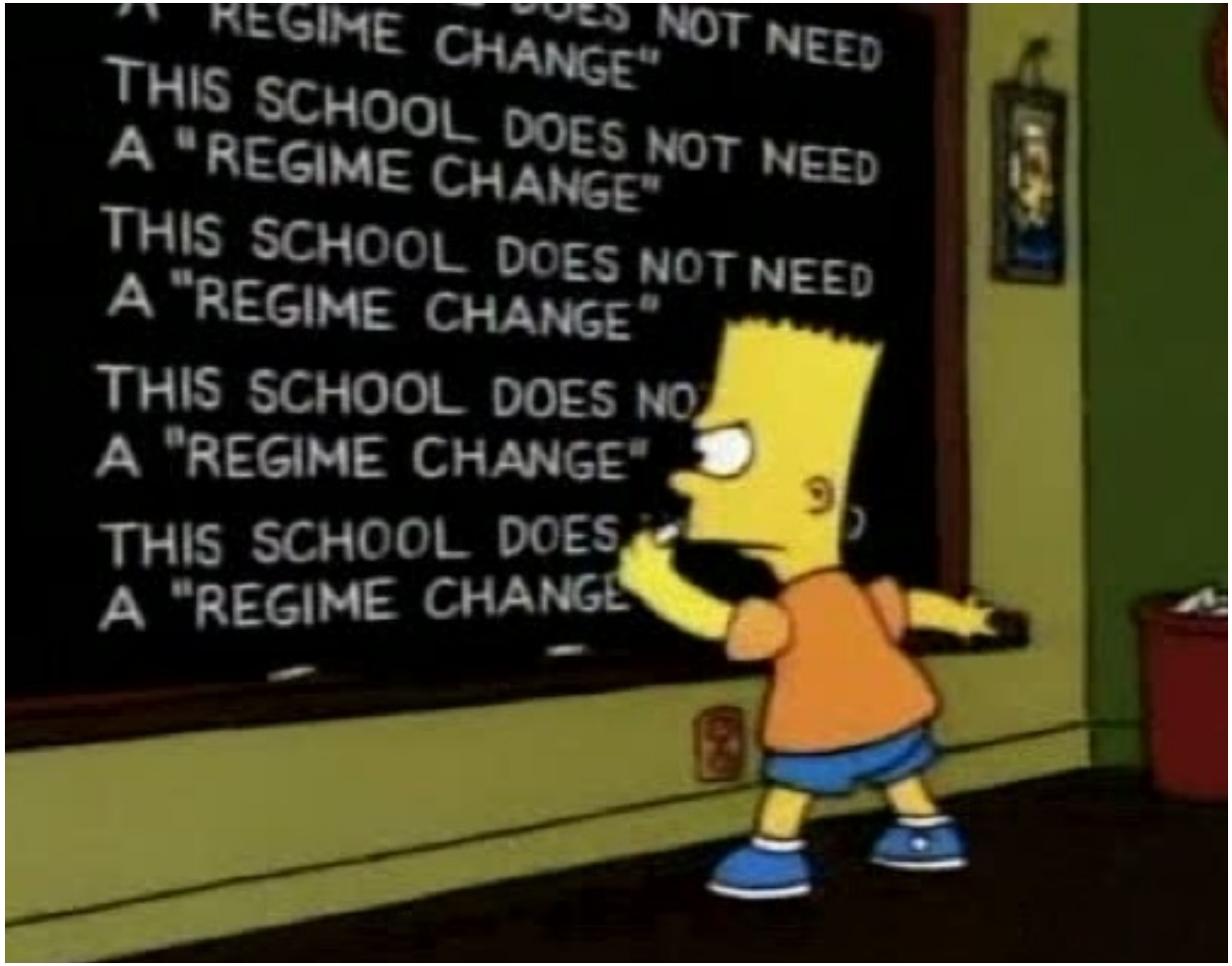
Thank you

gfay@umassd.edu

github.com/gavinfay/regimeswitch

www.thefaylab.com

@gavin_fay



Some suggested reading

- A'mar, Z. T., Punt, A. E., & Dorn, M. W. (2009). The impact of regime shifts on the performance of management strategies for the Gulf of Alaska walleye pollock (Theragra chalcogramma) fishery. *Canadian Journal of Fisheries and Aquatic Sciences*, *66*(12), 2222-2242.
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- Szuwalski, C., and Punt A. E. 2013. Fisheries management for regime-based ecosystems: a management strategy evaluation for the snow crab fishery in the eastern Bering Sea. – ICES Journal of Marine Science, 70: 955–967.
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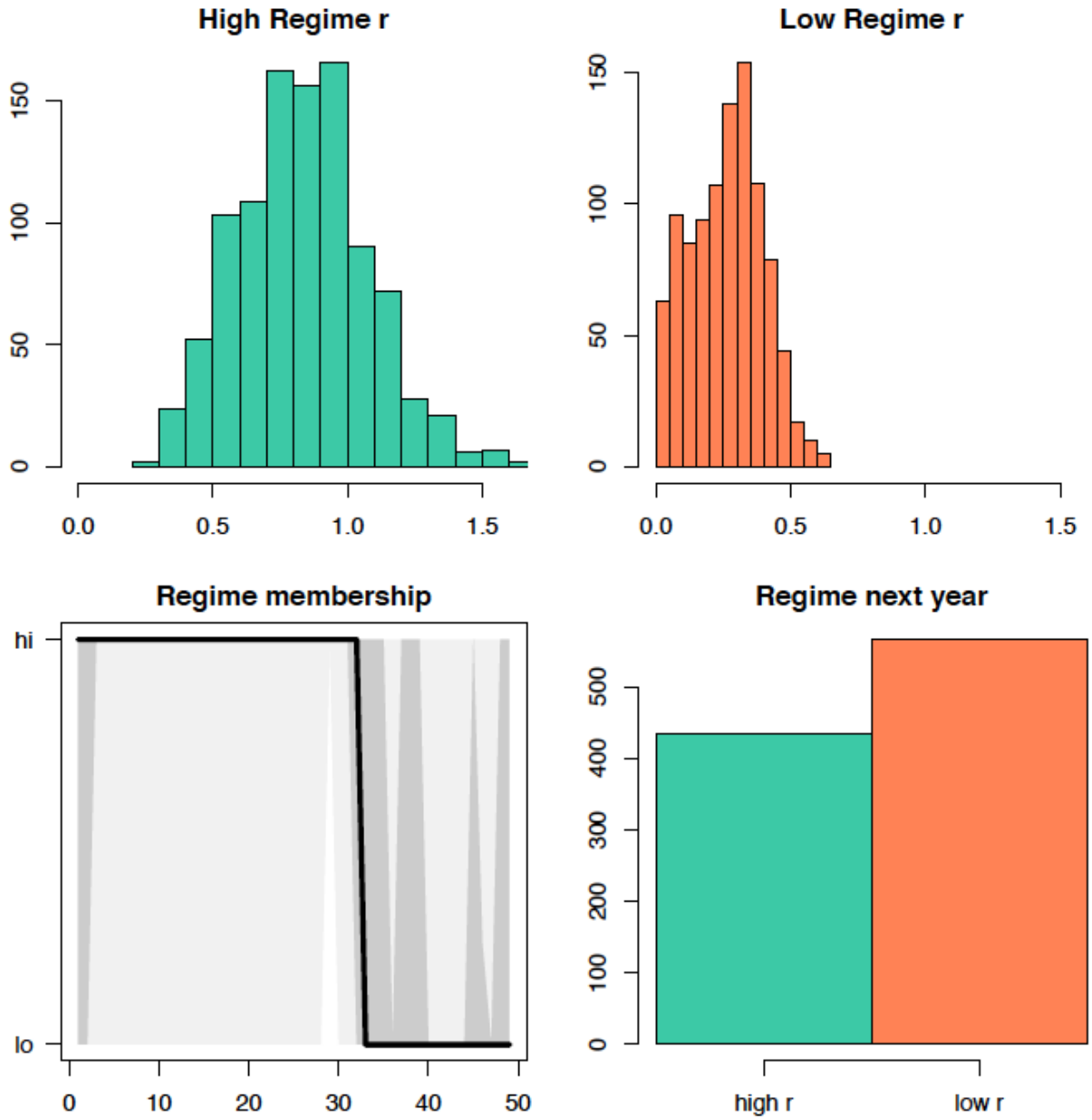
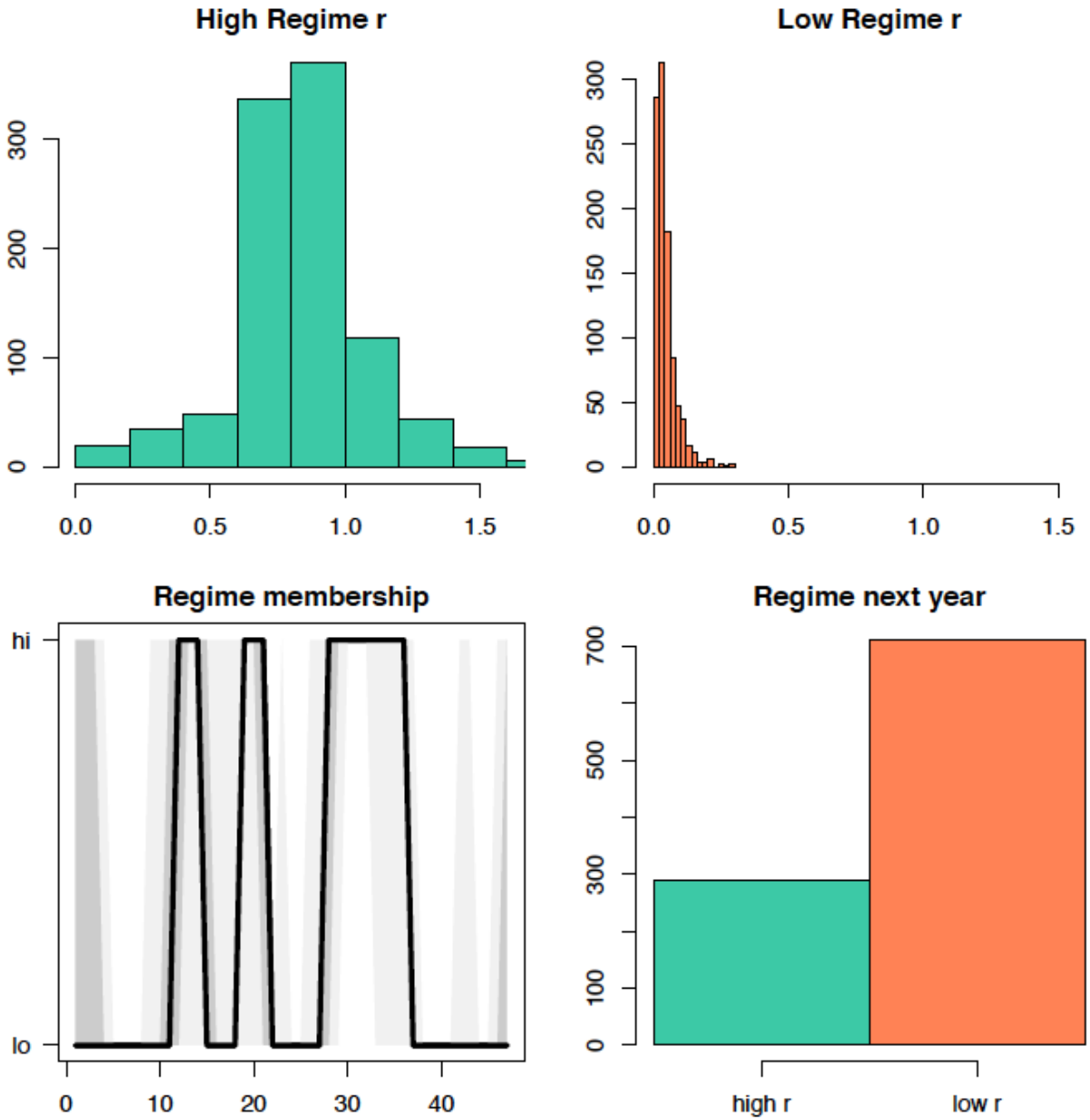
- Vert-pre, K. A., Amoroso, R. O., Jensen, O. P., & Hilborn, R. (2013). Frequency and intensity of productivity regime shifts in marine fish stocks. *Proceedings of the National Academy of Sciences*, *110*(5), 1779-1784.
- Wayte, S. E. (2012). Management implications of including a climate-induced recruitment shift in the stock assessment for jackass morwong (*Nemadactylus macropterus*) in south-eastern Australia. *Fisheries Research*.

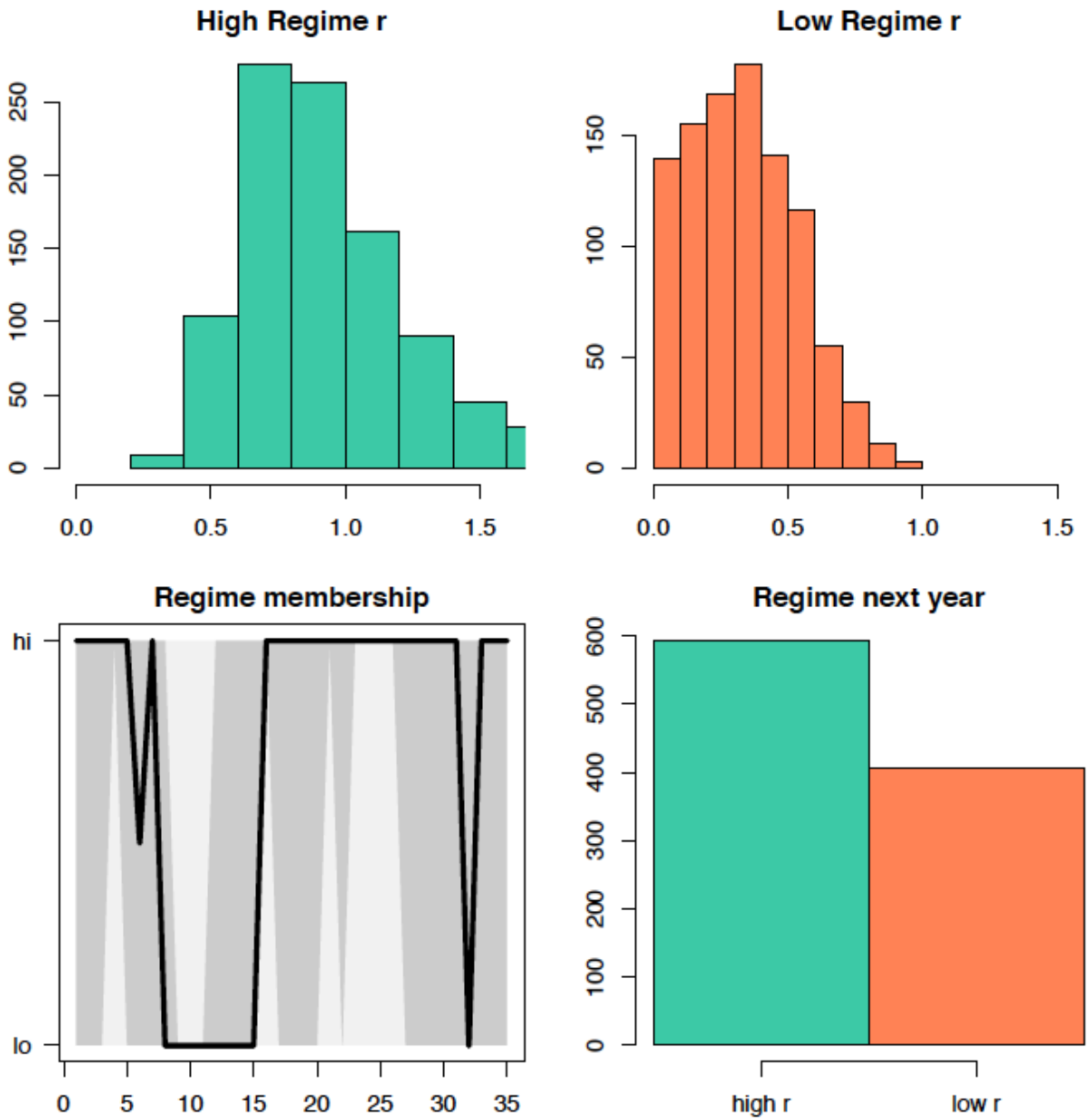
Georges Bank cod: Two regimes



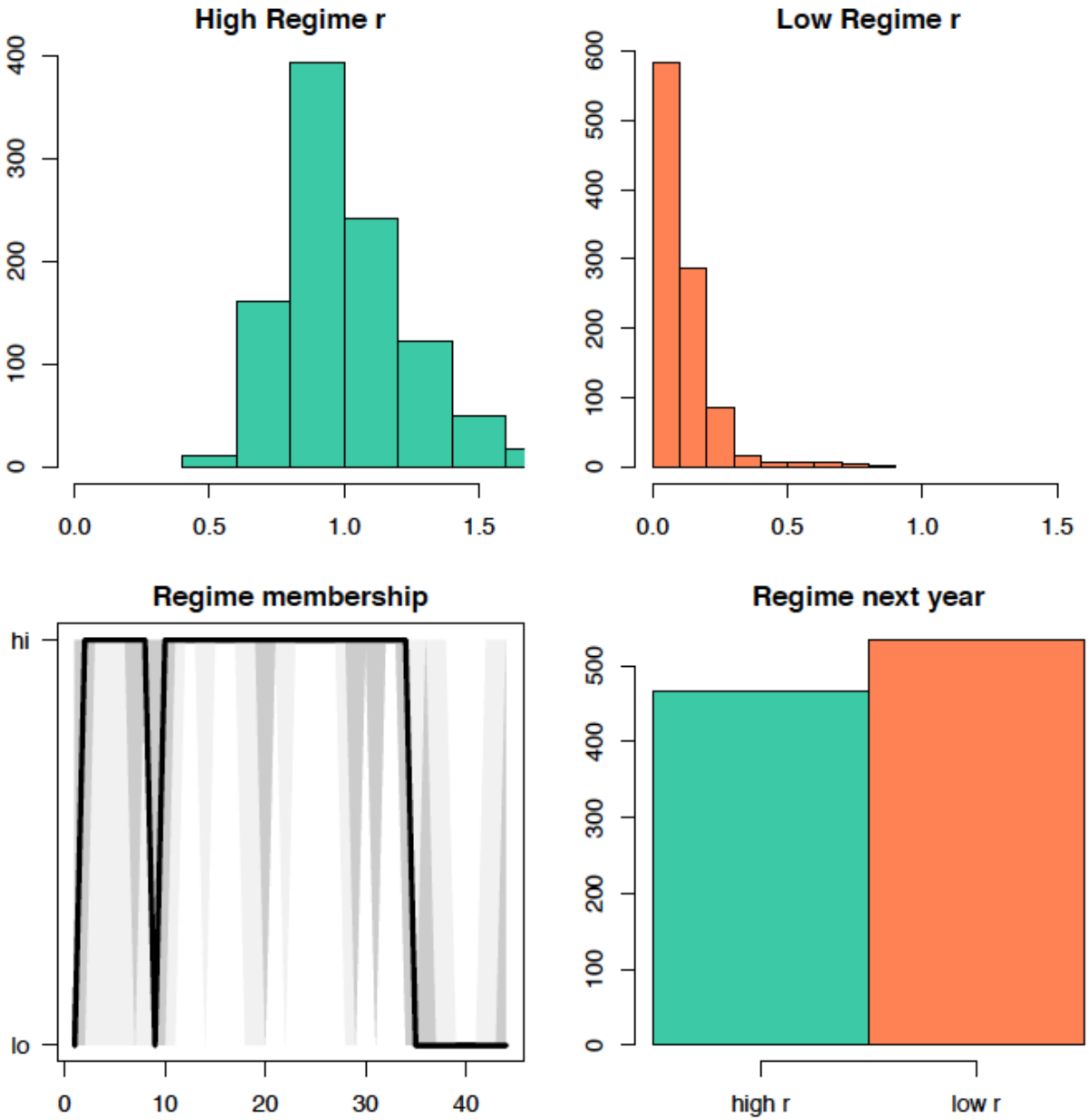
Gulf of Maine haddock: Two regimes



Georges Bank Yellowtail: Two regimes



SNE winter flounder: Two regimes



Estimation

$$L(D_t \mid \underline{\theta}) = \sum_{m=1}^{M} (D_t \mid \text{Regime}_t = m) P(\text{Regime}_t = m)$$

- P(Regime=m) can be decomposed into prior information both forwards and backwards in time ('forwards-backwards' algorithm).
- Not trivial when also coinciding with evolution of a continuous state variable.
- Other ML options, Kalman filter approximation, EM algorithm.
- Or, treat the states as discrete parameters

Application: Schaefer model with regimes in *r*

- Assume intrinsic growth rate follows regimes

$$B_{y+1} = \left(B_y + r_y(1 - B_y / K) - C_y\right)e^{\varepsilon_y}$$

$$r_y = \tilde{r}(\text{Regime}_y)$$

$$\text{Regime}_y \sim dcat(\,\Gamma[,\text{Regime}_{y-1}])$$

$$I_y = qB_y e^{\eta_y}$$

- Additional parameters: extra *r*, transition probabilities (2), Regime state distribution in initial year.

Marginal state-space / HMM likelihood

$$L\left(\underline{\theta} \mid D\right) = \int_e \prod_{t=1}^{T-1} \sum_{m=1}^{R} L\left(D_t \mid \underline{\theta}, \text{Regime}_t = m\right) P\left(\text{Regime}_t = m\right) de$$