How to test, use and manage sardine-anchovy-chub mackerel cycles

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- Acknowledgement: Organizers, G.Hunt, M.Kishi, A.MacCall, Y.Watanabe, Y. Watanuki, A.Yatsu, Secretariats

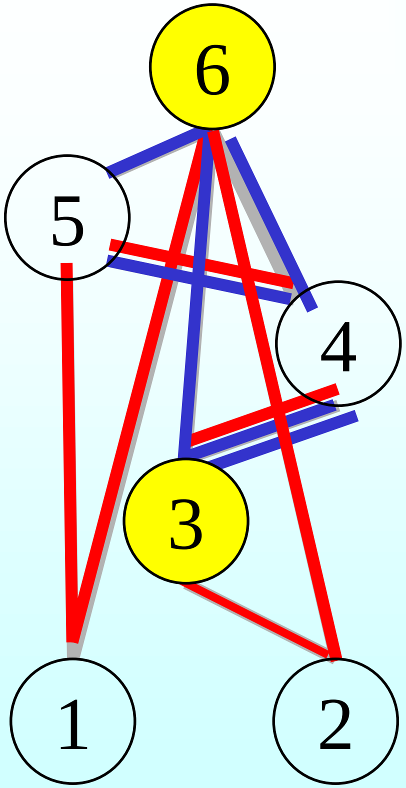
http://risk.kan.ynu.ac.jp/matsuda/2004/041020p.ppt

Overview

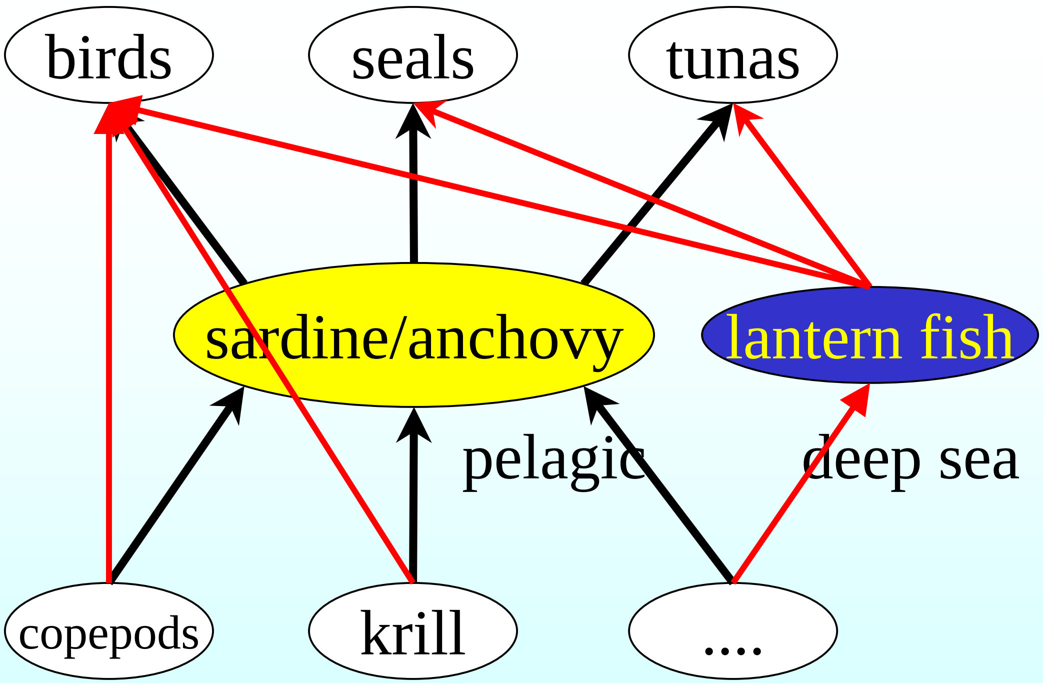
- **What is one of the most important knowledge in community ecology?**
- Can we predict the next dominant among small pelagic fishes?
- How much complexity do we need?
- Will Pacific chub mackerel recover?
- Be conscious of unknowns and unknowable

What is one of the most important knowledge in community ecology?

- **Indeterminacy** in indirect effects of community interactions (Yodzis 1988);
- From sensitivity analysis, the total effect between species is positive or negative even though process errors exist in growth rate;
- The **"vulnerability"** is not common for all species, and changes with conditions (evolutionary ecology).



Wasp-waist , is this illusion?



- Anyway, we need to investigate how to fluctuate the total biomass of small pelagics.

I still recommend eating small pelagics

- Catch of small pelagics is still much smaller than consumption by top predators.
- Total biomass of top predators may decrease in the 20th century.
- Some species when it is rare is overfished.
- Eating small pelagics is definitely smaller impact on eating higher trophic levels.

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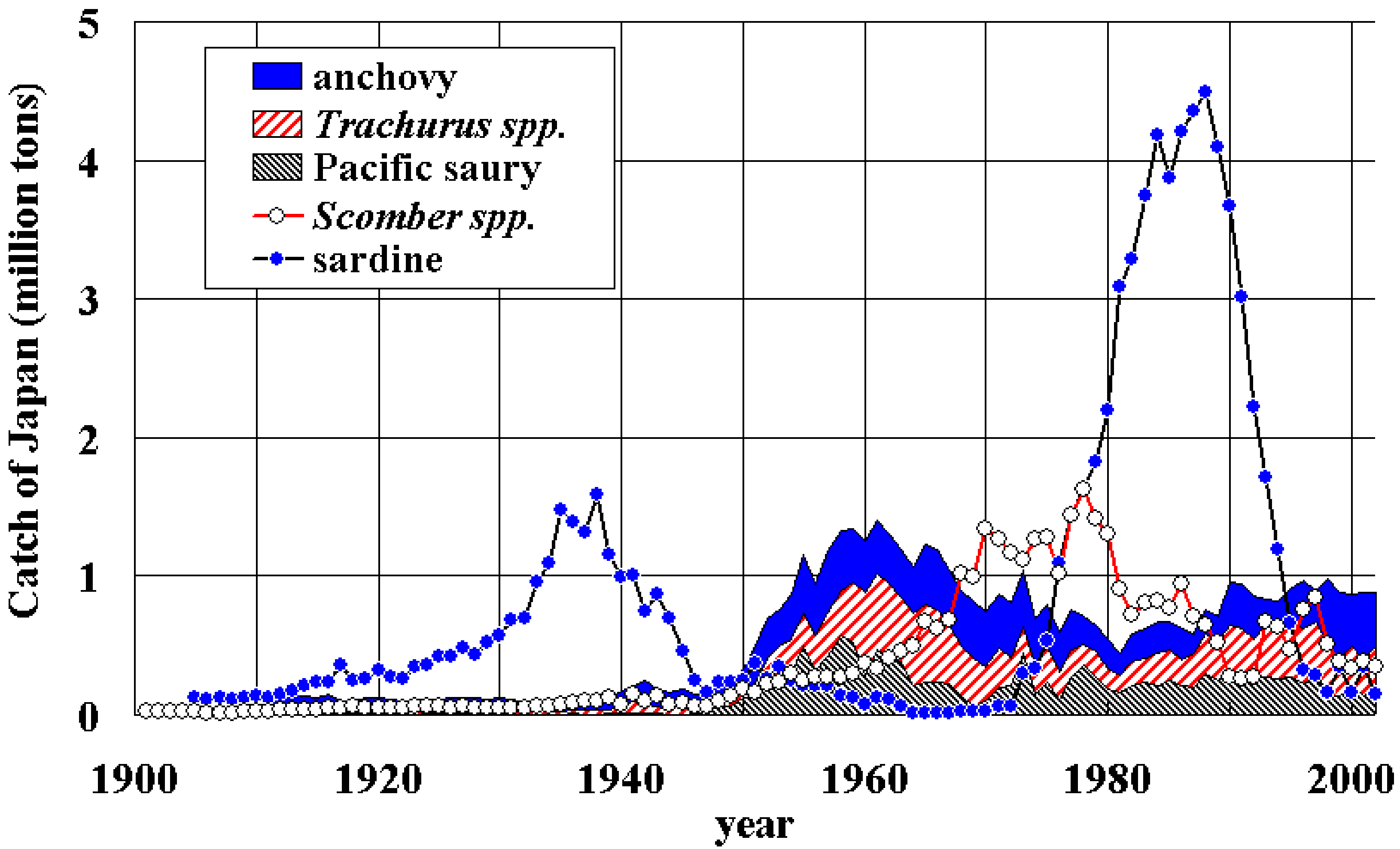
Species replacement among pelagic fishes

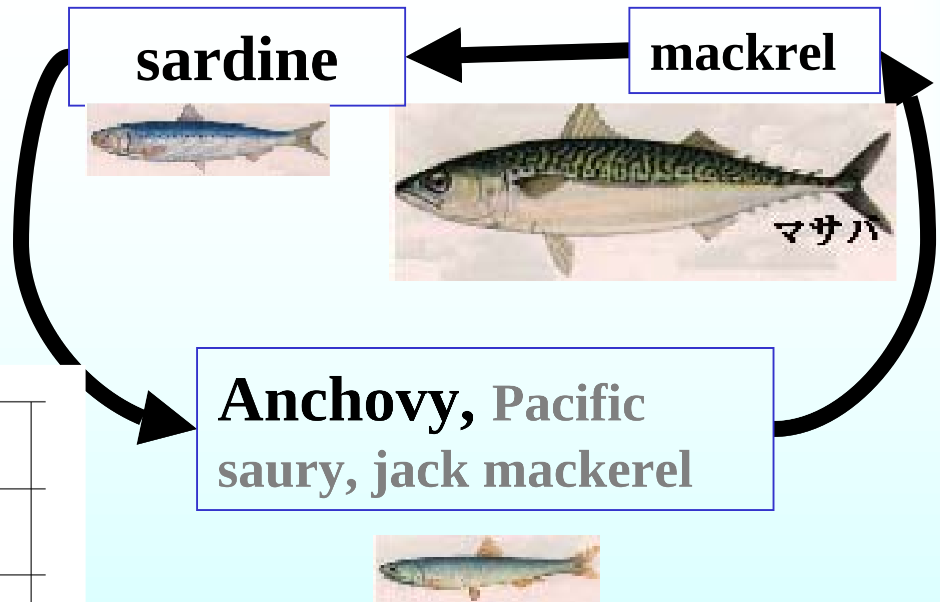


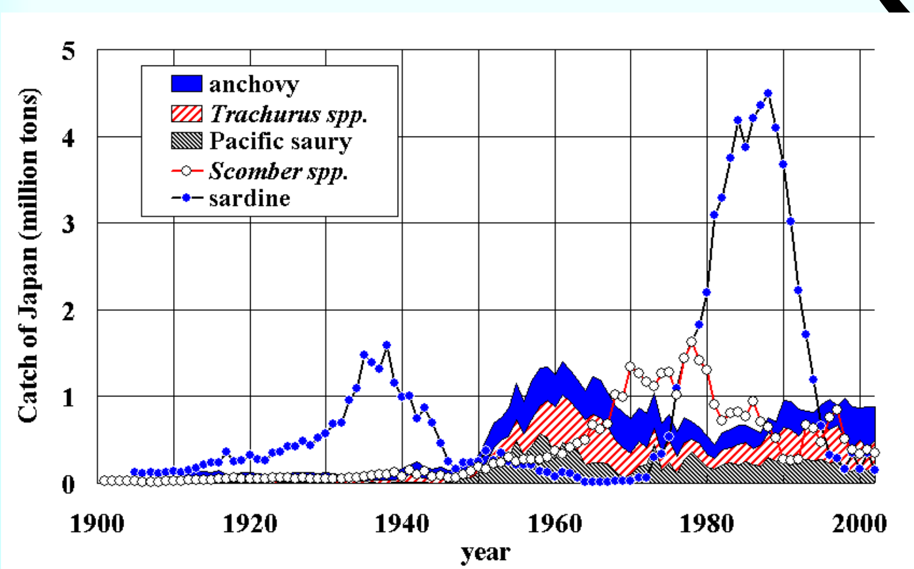
updated after Matsuda & Katsukawa (2002 Fish Oceanogr 11:366)

Cyclic Advantage Hypothesis for "sardine-anchovy-chub mackerel cycles"

The next dominant is anchovy –

The second next is chub mackerel





Matsuda et al. (1992) Res. Pop. Ecol. **34**:309-319

Possible combination between regime shift and species interactions

- When sardine increased, water temperature differed between off Japan and off California (McFarlane et al. 2002).
- A possible answer: "Temperature does not solely determine the sardine's stock dynamics."
- Climate change is a trigger for species replacement (Matsuda et al. 1992).

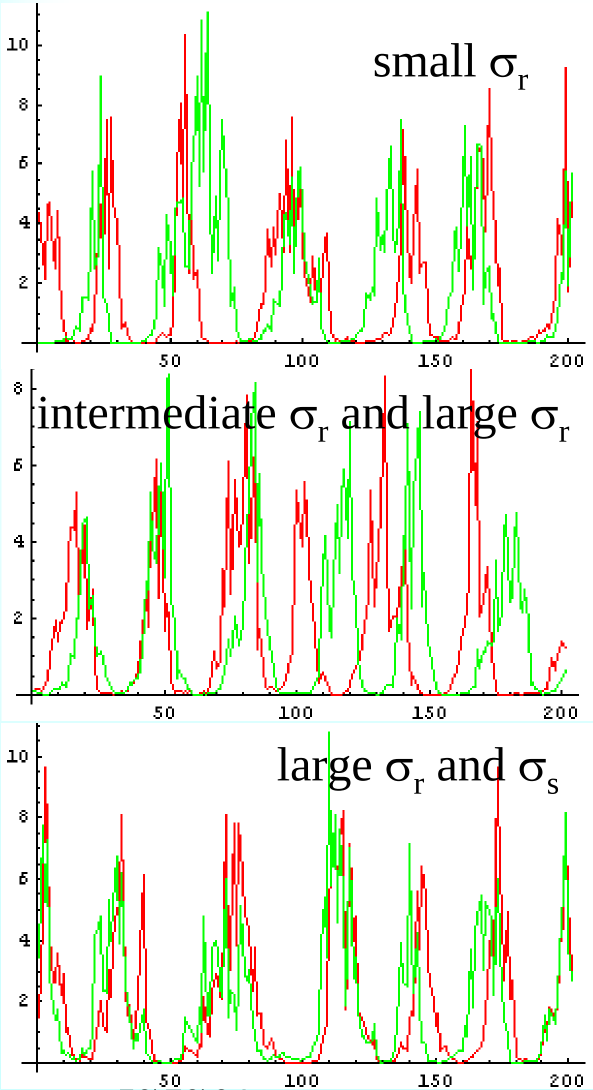
Global regime shift drives synchronicity

- We consider a cyclic-advantage model:

$$N_{ij}' = c + N_i \exp[r_{ij}(t) - a_{i1}N_{i1} - a_{i2}N_{i2} - a_{i3}N_{i3}]$$

- for species i (=1,2,3) in region j (=1,2);
- $r_{ij}(t)$ positively correlates between species (i) and between regions (j).
- σ_r: inter-regional correlation in $r_{ij}(t)$.

Simulated effect of "regime shift" σ_r & correlation between species σ_s



- If σ_r is small, **no synchronicity**; sardine increased off Japan and sardine/anchovy increased off California independently.
- If σ_r & σ_s are large, sardine increased off Japan almost when some species increased off California (**incomplete synchronicity**);
- If σ_r is large and σ_s is small, sardine increased both off Japan and California **simultaneously**.
- Which is true?

Sardine-anchovy-mackerel cycle hypothesis ...

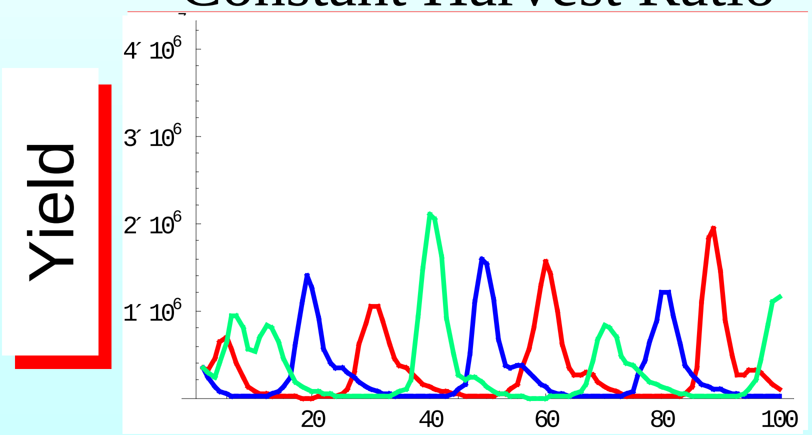
- is falsifiable because the next dominant is predictable.
- encourages multiple species management (target-switching; Katsukawa & Matsuda 2003 Fish Res 60:515)
- does not predict when the next replacement occurs (depending probably on regime shift...)

What is target-switching in fisheries?

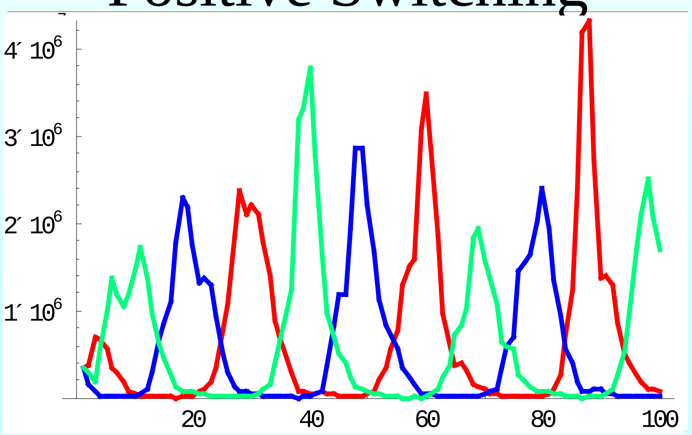
- Fishery that focuses its effort (f_i) on a temporally abundant species or stock *i*.
  $f_i \propto B_i / \Sigma B_i$.

•It saves rare stock, increases total catch.

Constant Harvest Ratio



Positive Switching



Katsukawa & Matsuda (2003 Fish. Res)

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Seek simplicity, but distrust it

–Begon, Harper & Townsend (1986) "Ecology: Individuals, Populations and Communities“

Opposite standpoint:

- **Seek complexity, and trust it.**
  Include all factors and data into the model

There are two types of models:

- **Eye-opening (“Remove scales on eyes”)**
- **Mystifying (“Smoke around the audience”)**

Seek simplicity, but distrust it

- **Make a simple model that only includes factors that are statistically/biologically evident or indispensable to obtain reasonable results.**
- **Include process- & measurement- errors.**
- A **simple model with errors** can explain the data if it does not include wrong factors.

Benefits of simple models with errors (SMwE)

SMwE

- **Easy to intuitively understand if reasonable**
- **Smaller degree of freedom**
- **Exclude only infeasible assumptions**
- **Accept a wide range of scenarios**
- **SMwE is useful in risk analysis**

Complex models

- **Difficult to make intuitive interpretation**
- **Choose all para-meters by maximum likelihood;**
- **Overfitting to the past data**
- **Predict a unique future under each scenario.**

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Q & A

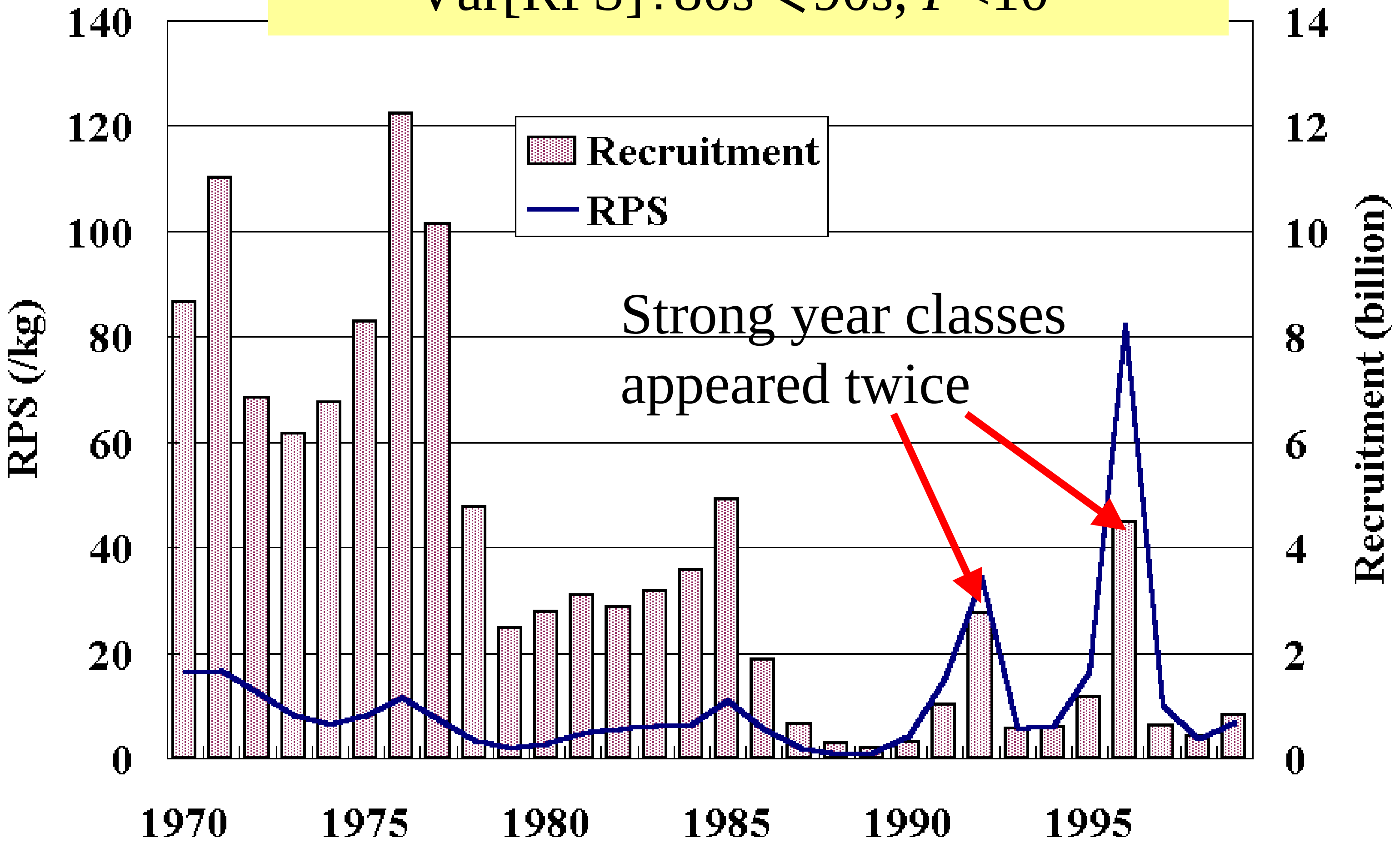
I have predicted, the next dominant to anchovy is chub mackerel...

Q: Will western Pacific chub mackerel really recover?

A: It depends on the fishing pressure.

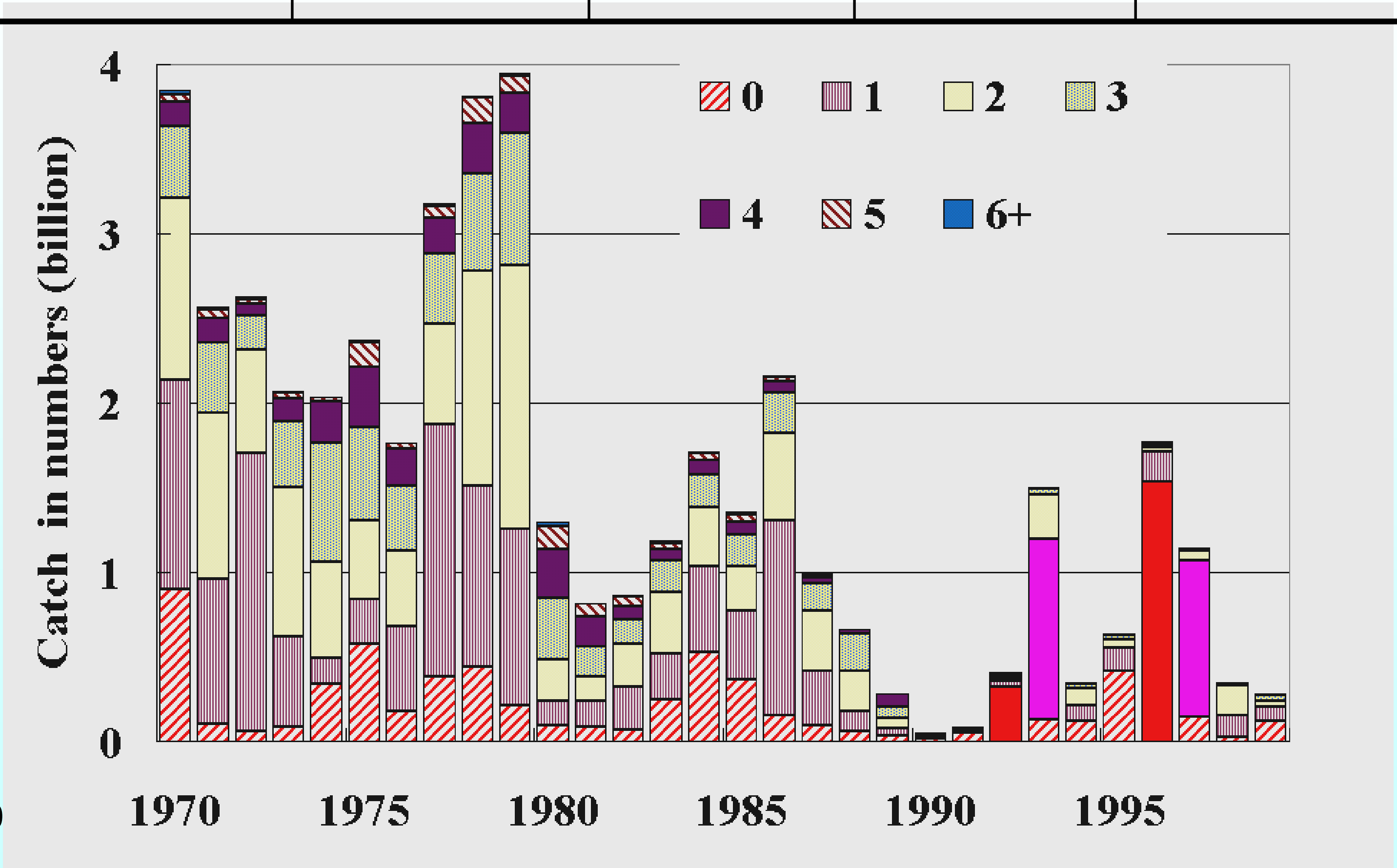
Large fluctuation of recruitment

Var[recruitment]: 80s > 90s, P<0.3%
Var[RPS]: 80s < 90s, $P<10^{-7}$



Strong year classes were caught before the age at maturity

	1970s	1980s	1990s	1993-
%immatures	**65.0%**	**60.0%**	**87.0%**	**90.6%**



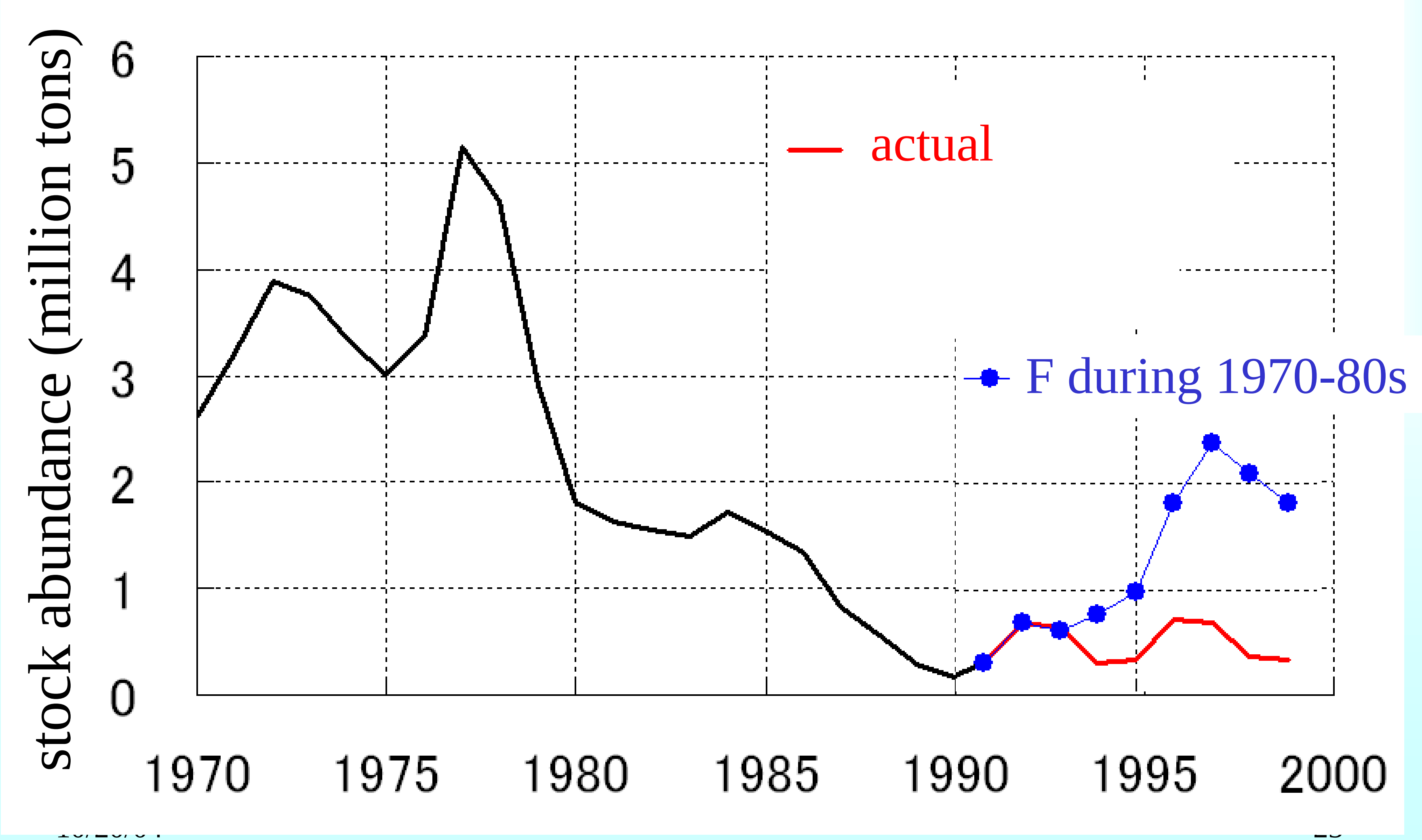
Risk assessment of stock recovery plan ("SMwE Operating Model")

- Start age structure of the current stock;
- Future RPS (α_t) is randomly chosen from the past 10 years estimates of RPS. (include process errors)
- $N_{0,t} = \mathrm{SSB}_t\, \alpha_t / (1 + \beta\, \mathrm{SSB}_t)$
- $N_{a+1,t+1} = N_{a,t} \exp[-M - F_a]$ (a=0,1,...5, "6+")
- $C_{a,t} = N_{a,t}\, \mathrm{e}^{-M/2} F_a w_a$

Kawai,…,Matsuda, Fish. Sci. 2002

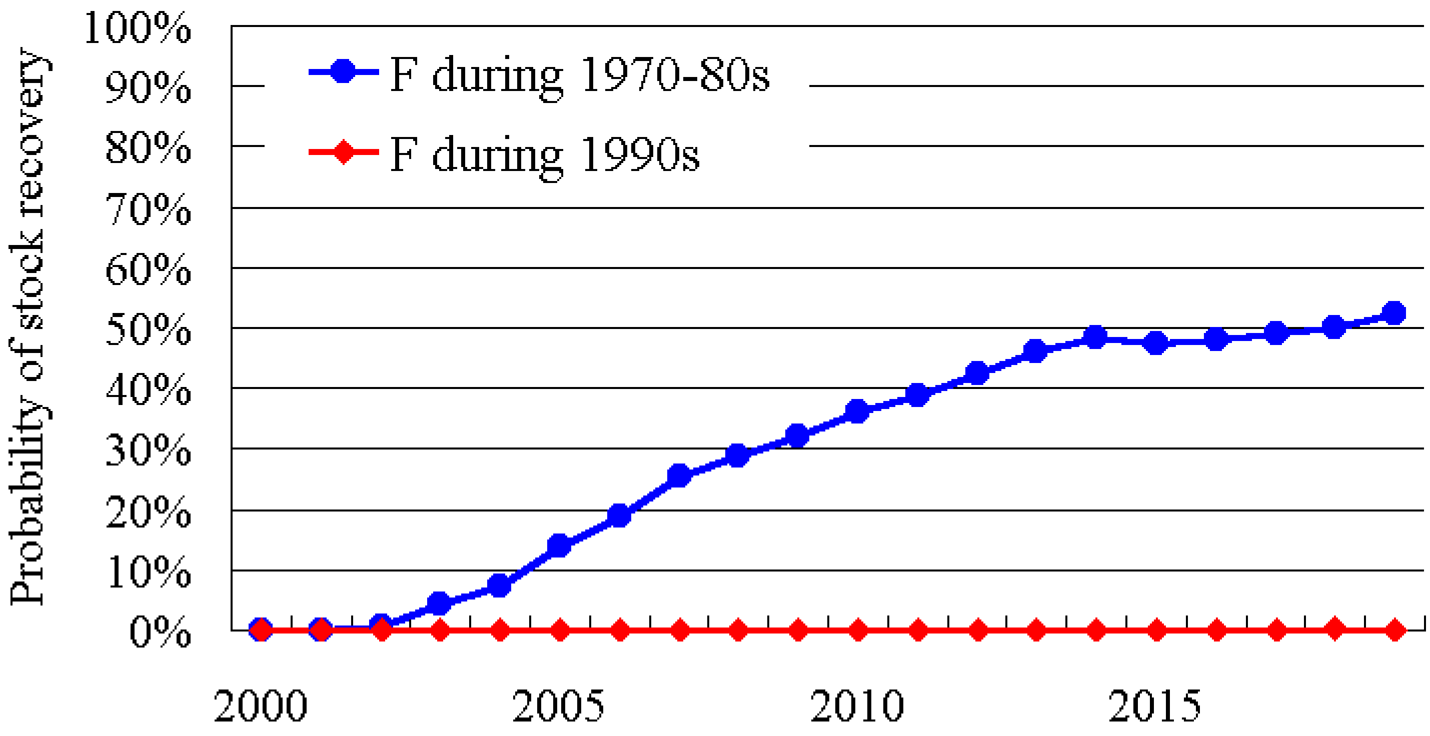
Fishers missed chance of recovery

Kawai,…,Matsuda, Fish. Sci. 2002



Probability of stock recovery

Kawai et al. (2002: *Fish. Sci*.**68**:961-969)



1990s is Japan's "lost 10 years".

Future of Pelagic Fish Populations in the north-western Pacific:

- If overfishing of immatures continues,
  - Chub mackerel will not recover forever;
  - Do not catch immatures too much.
- And if cyclic advantage hypothesis is true,
  - Sardine will not recover forever either;
  - The overfishing is an **experiment** for my hypothesis. (Adaptive mismanagement)
  - A mackerel-fishery regulation began in 2003.

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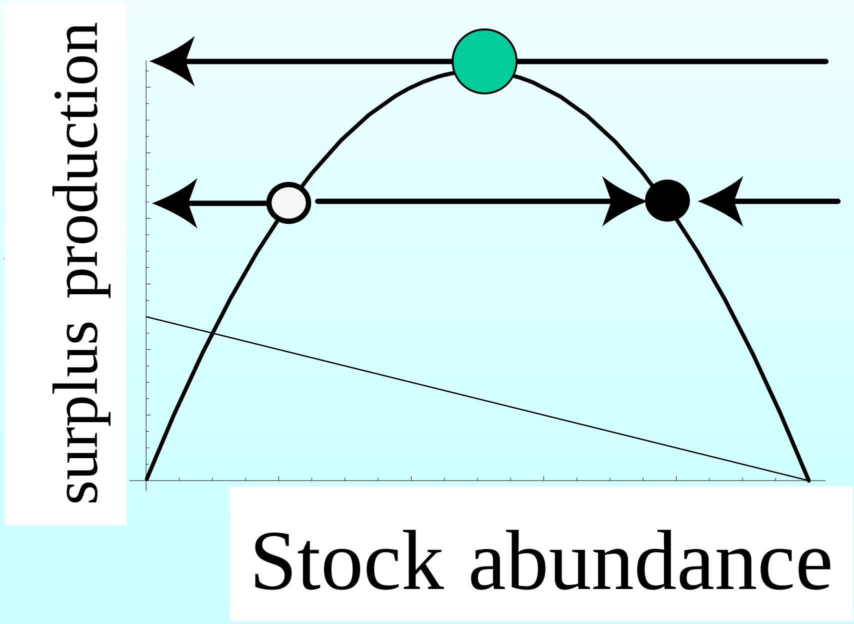
Requiem to Maximum Sustainable Yield Theory

- Ecosystems are usually uncertain, non-equilibrium and complex.
- MSY theory ignores all the three.
- Carrying capacity is defined under constant environ. & single sp. model.
- CCCC ????



Be conscious of unknowns and unknowable (cf CoML's slogan)

- Seek a falsifiable hypothesis;
- Avoid type II errors (precautionary principle)
- Certify what is unlikely future
- Prepare the worst case (risk management)
- Design management to test hypotheses in the future (adaptive management)

Recommendations #1

1. Do fishing down in food items!!
   - Eat small pelagic fishes
2. Eat more fish, not use as fish meal!!
   - Feed cows on grass, not corns (“Beyond Beef”)
3. Reduce discards before and after landings (our dishes);
4. Establish food market of temporally fluctuating pelagic fishes

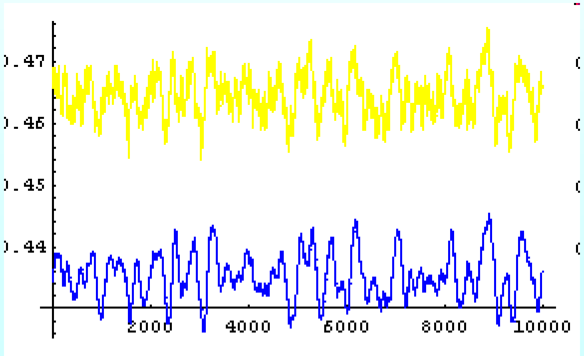
Recommendations #2

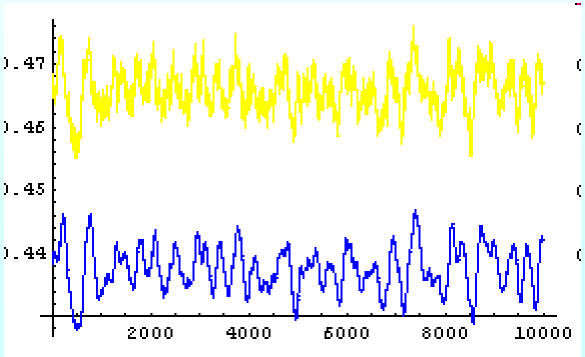
5. Switch a target fish (species replacement)
6. Conserve immatures
   - & Save a chance of multiple reproduction
7. Monitor "ecosystems" (not only target)
8. Improve technology for selective fishing
9. Conserve both fishes and fisheries;
   - unsustainable agriculture and forestry are problems rather than small pelagic fisheries

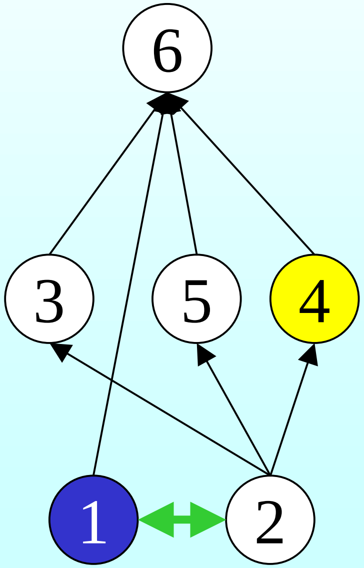
Thank you for invitation!!

I examined a model...

- $\Delta \mathbf{N} = (\mathbf{r}_t + \mathbf{A}.\mathbf{N})\mathbf{N}$
- $\mathbf{r}_t = \mathbf{r}^* (1+\xi_t)$ process errors
- ξ_t: random variable between -.1 and .1;





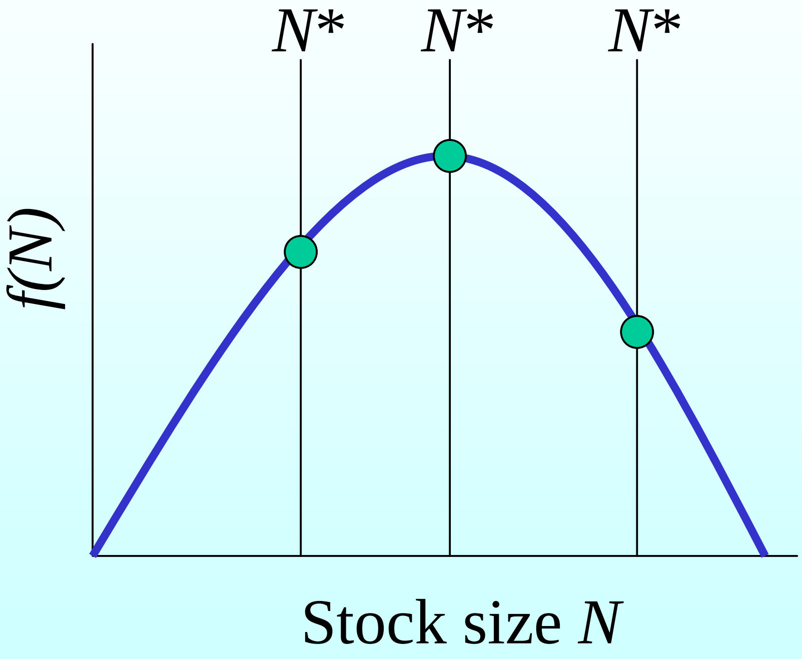


Feedback control in fishing effort is powerful...???

$$\frac{dN}{dt} = f(N) - qEN \qquad \frac{dE}{dt} = U\left(N - N^*\right)$$

A straw man says;

- Even though the MSY level is unknown, the feedback control stabilizes a broad range of target stock level *N**.



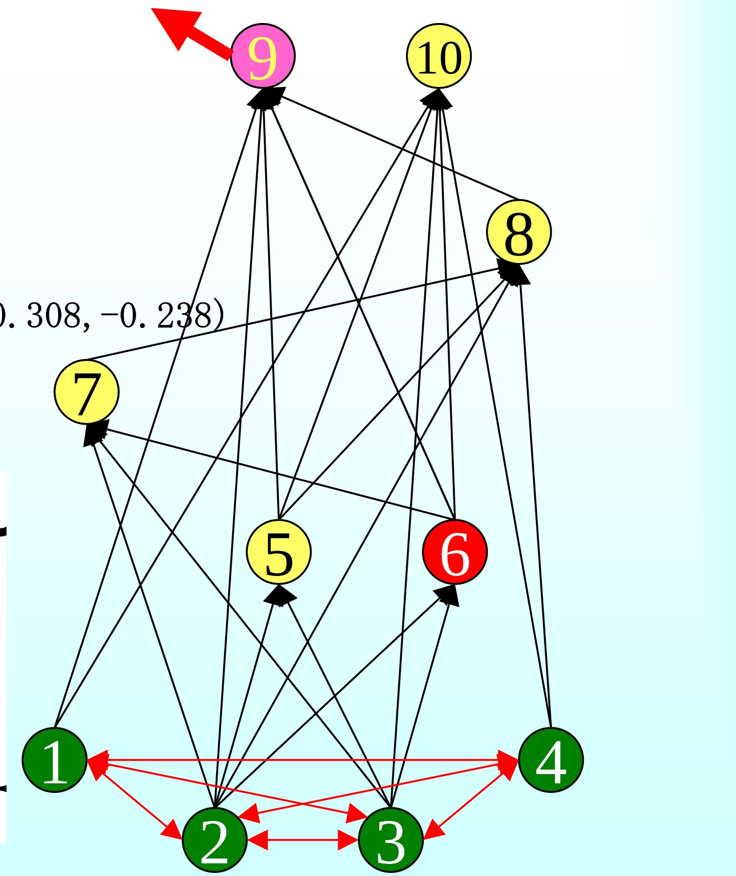
Feedback control with community interactions also result in undesired outcomes.
(Matsuda & Abrams in preparation)

$$\frac{dN_i}{dt} = \left(r_i + \sum_j a_{ji} N_j - q e_i \right) N_i$$

r = (0.454, 1.059, 1.186, 0.247, −0.006, −0.028, −0.059, −0.704, −0.308, −0.238)

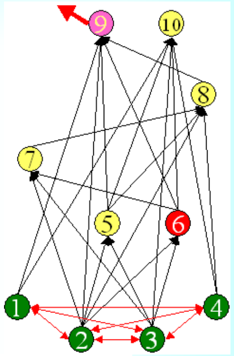
$A = (a_{ji}) =$

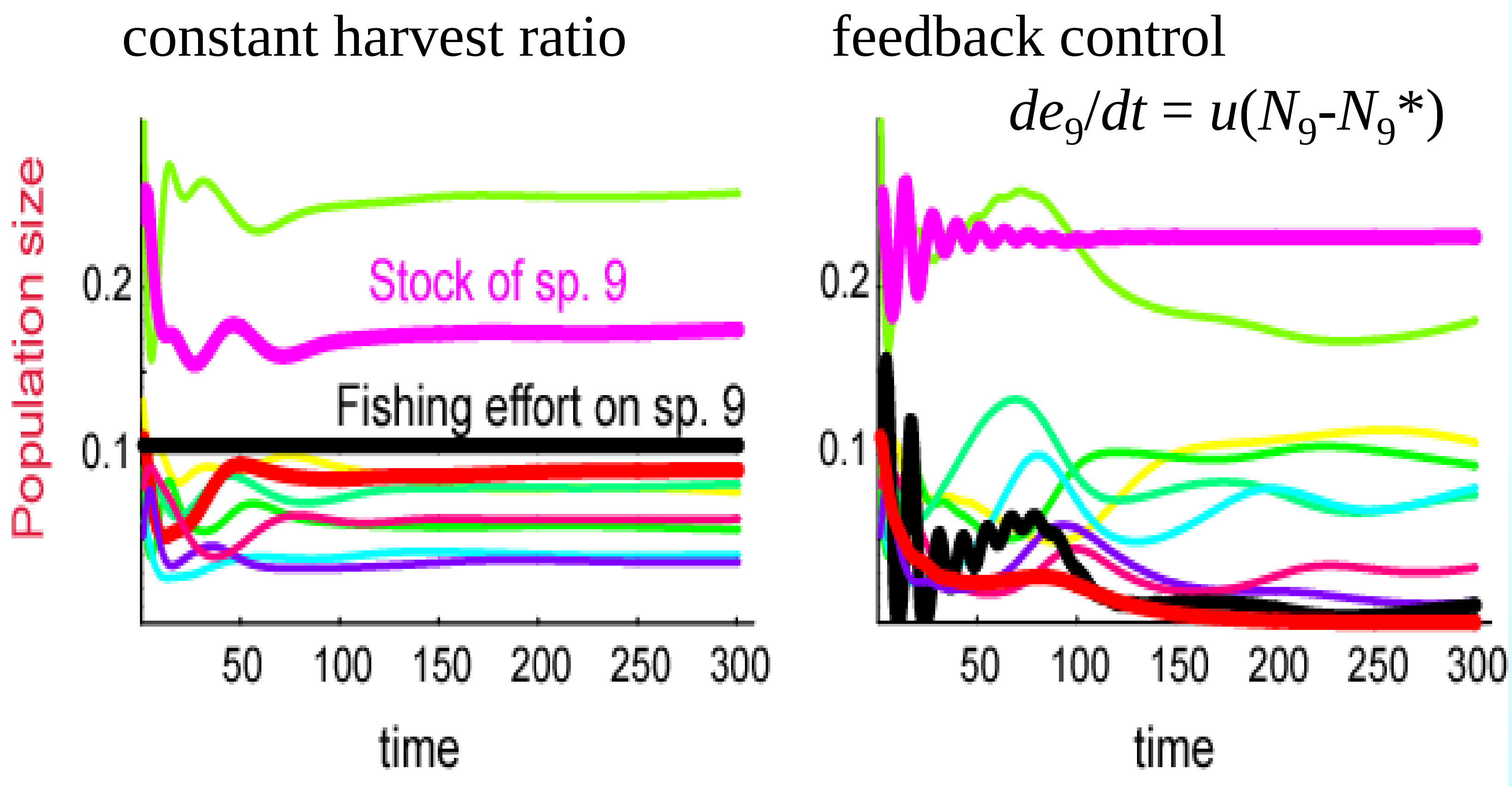
-1.	-0.74	-0.19	-0.31	0.	0.	0.	0.	-0.7	-0.46
-0.74	-1.	-0.87	-0.08	-0.46	-0.66	-0.48	-0.73	-0.84	0.
-0.19	-0.87	-1.	-0.96	-0.08	-0.14	-0.83	0.	0.	-0.68
-0.31	-0.08	-0.96	-1.	0.	0.	0.	-0.28	0.	-0.88
0.	0.46	0.08	0.	-0.1	0.	0.	-0.92	-0.15	-0.84
0.	0.66	0.14	0.	0.	-0.1	-0.01	0.	-0.5	-0.69
0.	0.48	0.83	0.	0.	0.01	-0.1	-0.56	0.	0.
0.	0.73	0.	0.28	0.92	0.	0.56	-0.1	-0.28	0.
0.7	0.84	0.	0.	0.15	0.5	0.	0.28	-0.1	0.
0.46	0.	0.68	0.88	0.84	0.69	0.	0.	0.	-0.1



$e_9 = 0.1,\ e_i = 0$

Feedback control may result in extinction of other species (sp. 6).





Remarks in adaptive ecosystem management.

- Single stock monitoring is dangerous
- Target stock level is much more sensitive than we have considered in single stock models.
- We must monitor not only stock level of target species, but traits of target species and species that interacts with target species.

Mixed Trophic Impact provided by Ecopath

- Mixed trophic impact (MTI)
- $B_j \cdot PB_j \cdot EE_j - \Sigma_j B_j \cdot QB_j \cdot DC_{ji} - EX_j = 0$ (balance)
- $FC_{ji} = B_j \cdot QB_j \cdot DC_{ji} / \Sigma_k B_k \cdot QB_k \cdot DC_{ki}$
- $q_{ij} = DC_{ij} - FC_{ji}$
  % of prey *j* in predator *i*'s diet - % of predator *i* among prey *i*'s predators)
- $\mathrm{MTI} = \Sigma_{k=1} \mathbf{Q}^k = (\mathbf{I} - \mathbf{Q})^{-1} - \mathbf{I}$
- Concept that Got Novel economy prize

What differs between Yodzis' sensitivity and mixed trophic impact?

- Total indirect effect through community interactions of a small change are evaluated by Yodzis' sensitivity matrix.
- $d\mathbf{N}/dt = \mathbf{f}(\mathbf{N}, p)$ (=0 at $\mathbf{N}=\mathbf{N}^*$, equilibrium)
- $\partial\mathbf{N}^*/\partial p = -(\partial\mathbf{f}/\partial\mathbf{N})^{-1}(\partial\mathbf{f}/\partial p)$
- Sensitivity is clear and understandable.
- I do not know ecological meaning of MTI.