Concept for fluctuating fish stocks

(1) Maximum sustainable yield (MSY) based on a density-dependent effect may only be an illusion!

(2) We should develop a new management procedure that does not assume the MSY theory.

Apr. 16, 2015

Kazumi Sakuramoto (TMSAT)

Contents (four points will be discussed)

I. The first point:

Does a density-dependent effect (DDE) truly exist in a stock-recruitment relationship?

- If a density-dependent effect does not exist, neither would the MSY.
- I first discuss a methodological problem to detect a DDE.

II. Why have we not noticed the misunderstanding regarding the concept of a stock-recruitment relationship (SRR)?

III. An example based on the new concept of SRR for the Pacific stock of Japanese sardines

IV. A preliminary analysis of the fluctuation mechanism in the recruitment of the Pacific stock of bluefin tuna

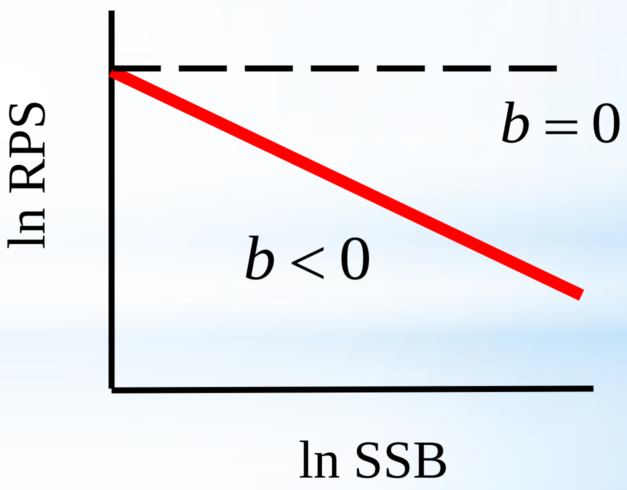
I. Does a density-dependent effect (DEE) truly exist in SRR?

Two methods have been commonly used.

One typical method is plotting the 'ln RPS' values against the 'ln SSB' (spawning stock biomass) values. Here, RPS denotes the reproductive success that is calculated by recruitment (R) over SSB.

$$\ln RPS = \ln a - b \ln S$$

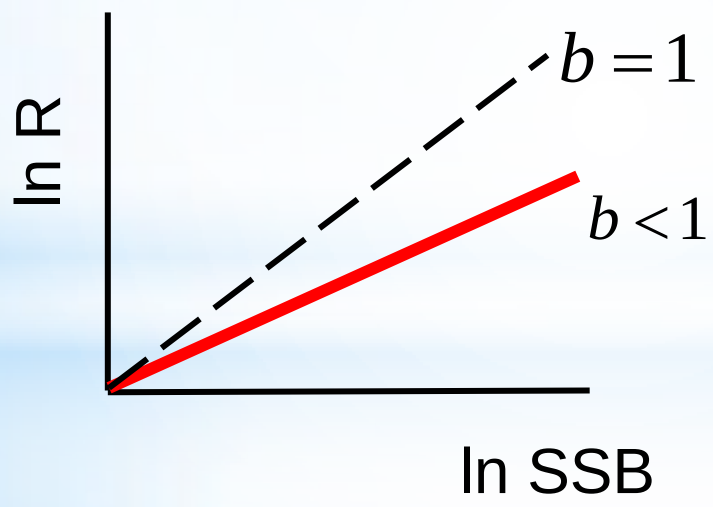
When the slope of the regression line is negative, it is thought that a density-dependent effect exists in the SRR.



The second method is plotting ln R values against ln SSB values.

When the slope of the regression line is different from unity, it is thought that a density-dependent effect exists in SRR.

$$\ln R = \ln a + b \ln S$$



When b = 1, then

$$\ln R = \ln a + \ln S$$

$$\Rightarrow \quad R = a \cdot S$$

This indicates a proportional model, and a DDE does not exist in the SRR.

However, these methods have critical defects.
I will first show the defect using a simple simulation.

For simplicity, let's consider the case when R and SSB were only observed during 3 years and the values all happen to be the same.

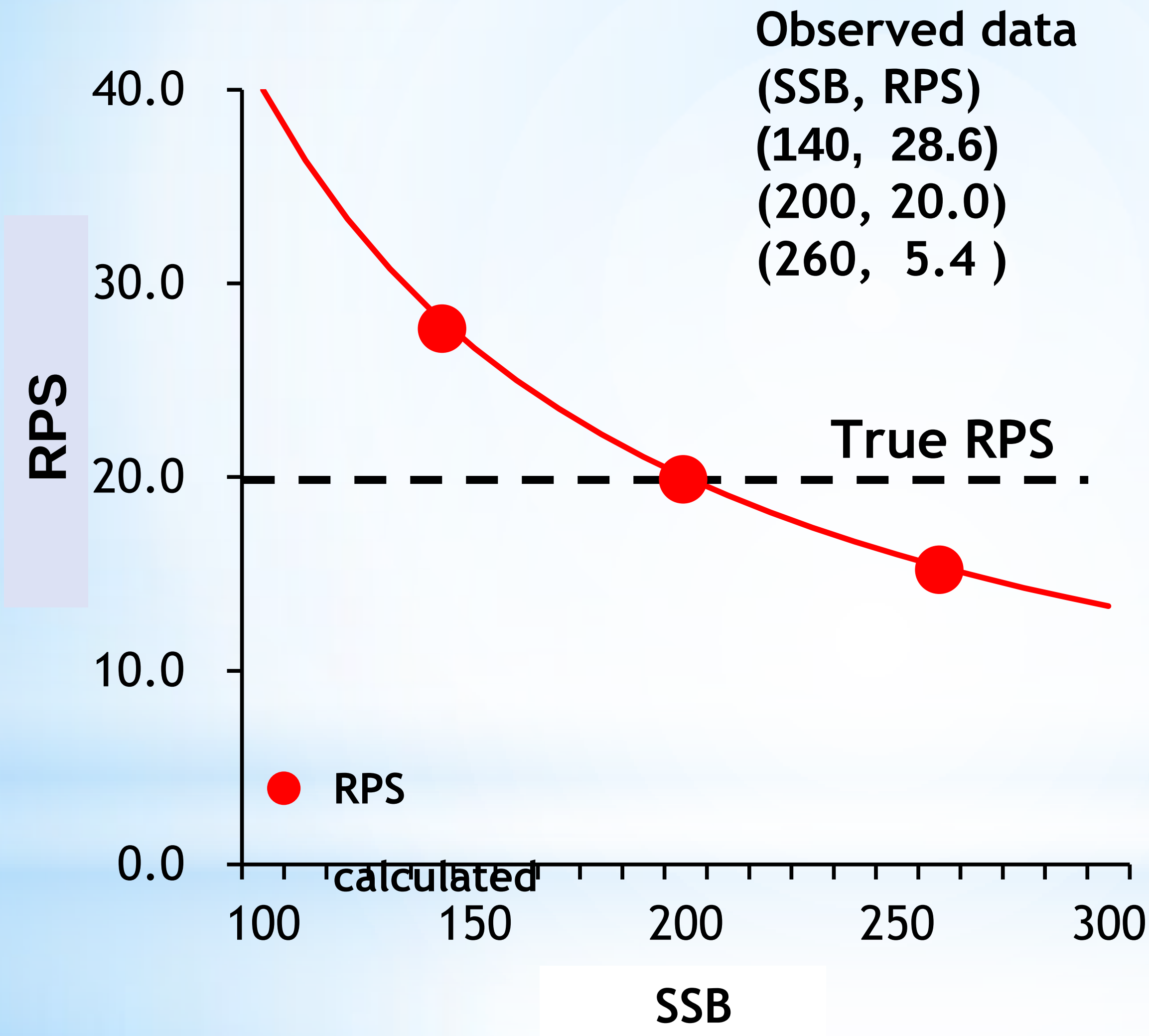
	R	SSB	RPS
1st year	4000	200	20
2nd year	4000	200	20
3rd year	4000	200	20

When observation errors are incorporated in SSB over 2 years:

For instance, let's consider the cases in which the SSB is overestimated or underestimated by 30%.

R	Observed SSB	Observed RPS
4000	200 (correct value)	20.0
4000	260 (overestimated)	15.4
4000	140 (underestimated)	28.6

When we plot the observed RPS against observed SSB:



When observation errors were incorporated, a DDE was erroneously detected.

When observation errors were added to both R and SSB, the results are essentially the same.

Under much more practical situations, the results are essentially the same.

An apparent decreasing trend appears!

That is, a serious defect exists in the method plotting ln RPS against ln SSB. However, this method has been commonly used and played an important role not only in fisheries science but also in biology.

Historically important discussions were held between two groups. One group believed that the DDE played an important role to explain the population changes, and the other completely denied the importance of a DDE. These discussions were conducted between Nicolson, Smith and others, and Andrewartha and Birch's group more than 60 years ago.

I'd like to briefly review those discussions.

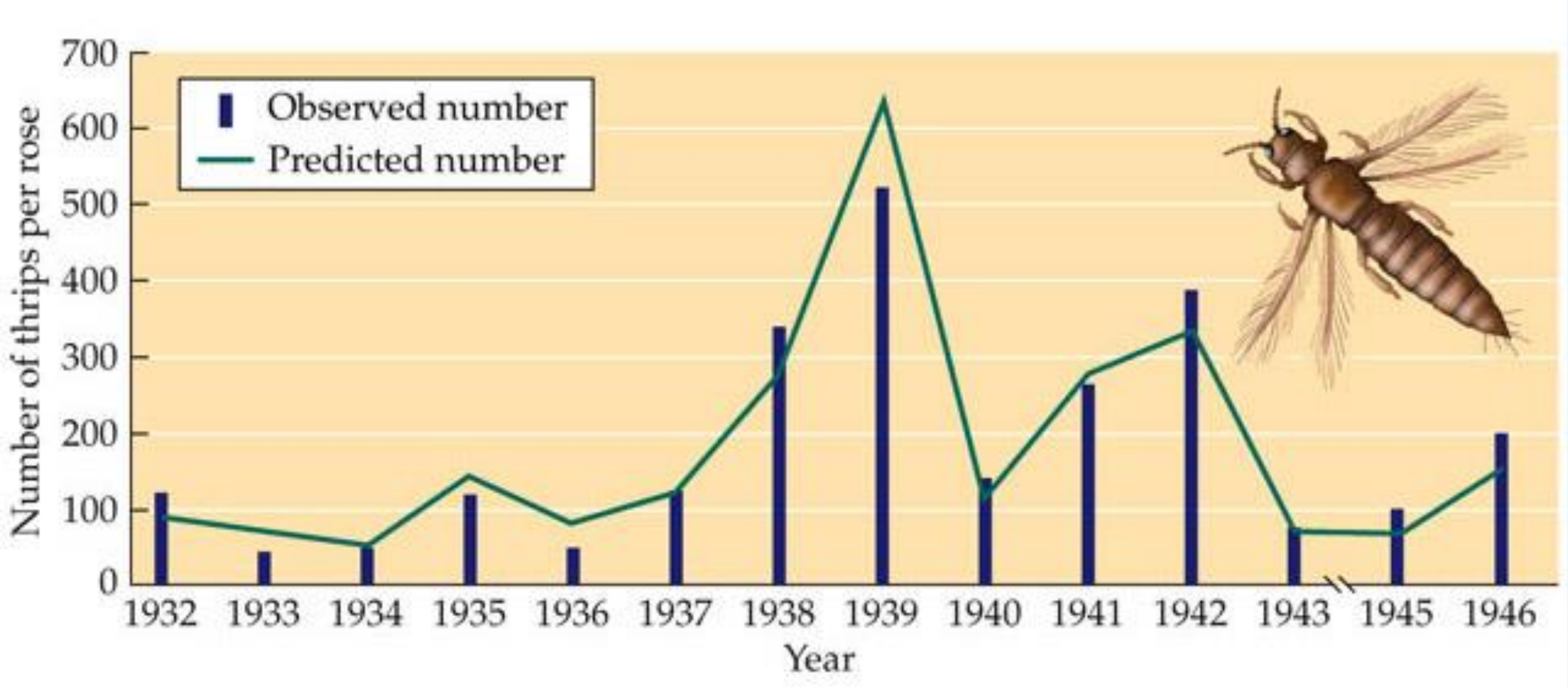
Andrewartha and Birch’s studies

- Andrewartha et al. (1948) observed the numbers of *Thrips imaginis* populations living on roses everyday at a rose garden in Australia from 1932 to 1938.
- *T. imaginis* is 1–5 mm in length. It infects roses and apple trees. Some 5,000 species of *T. imaginis* are known in the world.
- They continued to observe the numbers only for the Spring (October and November) from 1939 to 1943.
- Female *T. imaginis* spawn several eggs every day during their lifespan.
- The *T. imaginis* lifespan includes several stages.



Results of Andrewartha et al.'s 1948 analysis:

$(\log(n_i) = \log(n) + \log h(x_1) + ... + \log h(x_i))$



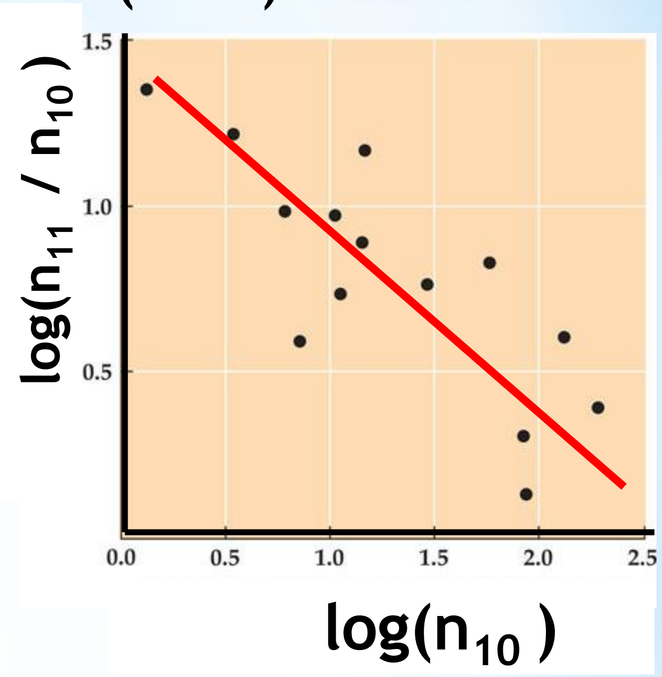
Andrewartha et al. (1948) showed that 78% of the variation in the numbers of *T. imaginis* populations in Spring could be explained by the precipitations and temperatures in the previous Autumn. A DDE could not be detected from the last 22% of variation. That is, Andrewartha et al. completely denied the existence of a DDE.

However, using the same data, Frederic Smith (1961) showed that a DDE was clearly observed in the plot of the increment of *T. imaginis* populations from October to November.

Contentious arguments occurred between Andrewartha’s group and Smith. Smith eventually won the debate, and the existence of the DDE is now accepted by many biologists.

However, I believe that Smith’s position is not valid, because he used the 1st method described above. I will explain this with simulations (Sakuramoto, 2014).

Analysis by Smith (1961)



Smith (1961) used the data from 1932–1945 (14 years). He insisted that a clear decreasing trend was observed.

These are the first 7 years' data collected by Andrewartha et al. (1948)

	1932-33	1933-34	1934-35	1935-36	1936-37	1937-38	1938-	Mean	Standard deviation
Apr.	0.65	0.38	0.79	0.41	0.52	0.30	0.54	0.51	0.17
May	1.37	0.59	1.16	0.79	0.91	0.48	1.04	0.91	0.31
Jun.	1.25	0.72	1.43	1.22	1.11	0.68	0.75	1.02	0.30
Jul.	0.64	0.74	0.83	-0.10	0.96	0.40	0.90	0.62	0.37
Aug	0.52	0.23	0.57	0.23	0.26	0.23	0.73	0.40	0.21
Sep.	1.53	0.45	0.77	0.74	0.63	0.66	1.71	0.93	0.49
Oct.	1.14	1.00	0.20	1.34	1.05	1.39	2.20	1.19	0.59
Nov.	2.13	1.89	1.56	2.13	1.61	2.49	2.76	2.08	0.44
Dec.	2.43	1.85	1.88	2.14	1.84	2.11	2.14	2.05	0.21
Jan.	1.58	1.19	1.16	1.20	0.77	1.19		1.18	0.26
Feb.	0.99	0.71	0.89	0.76	0.46	0.79		0.77	0.18
Mar	0.45	0.86	0.57	0.80	0.57	0.60		0.64	0.16

(logarithmic scale)

In accord with Smith (1961), I calculated the increment of *T. imaginis* populations from October to November using the artificial data.*

(1) I generated the artificial data from the normal distribution $N(m_{10}, SD_{10}^2)$ or $N(m_{11}, SD_{11}^2)$.
where m_{10} and SD_{10} denote the mean and standard deviation in October and m_{11} and SD_{11} denote those in November.

(2) I plotted $\ln(N_{11}/N_{10})$ against $\ln(N_{10})$ and calculated the slope of the regression line.

(3) I conducted1000 Monte Carlo simulations and counted the number of simulations of which the slope was significantly negative at the 5% significance level.

Results of the simulation including sensitivity tests when the standard deviations in Oct. or Nov. are 25% smaller or larger than the observed values. I also checked when the number of samples is changed from 7 to 14.

Number of samples = 7

		SD (Nov.)		
		0.44*0.75	0.44	0.44*1.25
	0.59*0.75	687	493	346
SD (Oct.)	0.59	849	687	529
	0.59*1.25	932	817	687

Number of samples = 14

		SD (Nov.)		
		0.44*0.75	0.44	0.44*1.25
	0.59*0.75	964	883	737
SD (Oct.)	0.59	999	964	914
	0.59*1.25	1000	995	964

* That is,

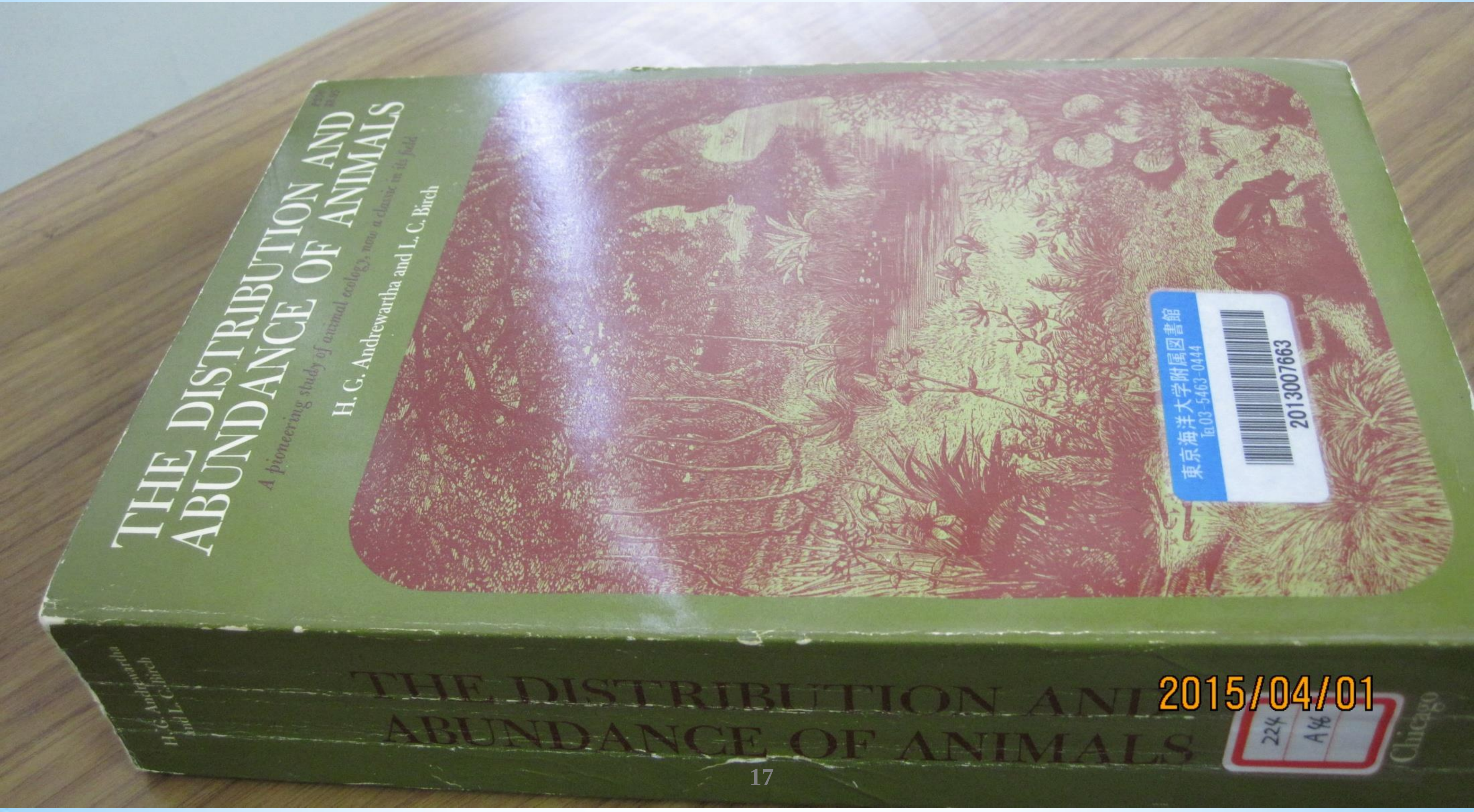
Even in the case in which the number of populations in October and November were randomly determined, almost all the slopes of the regression lines of ln(N_{11}/N_{10}) against ln(N_{10}) became significantly negative, and DDEs were erroneously detected.

The provability of the false results detected was more than 95% when the sample size was 14.

Therefore, the assertion by Smith (1961) is not valid and the probability that the claim by Andrewartha et al. is correct is high.

From the above discussion, the existence of the DDE is extremely doubtful.

Andrewartha and Birch published a book in 1954, “The Distribution and Abundance of Animals.” I believe that they are outstanding, great biologists and I respect their work from the bottom of my heart.



* **In the field of fisheries science, Quinn and Deriso (1999) had already noted the same points:**

① If a random sample was taken from the two log normal distributions with CVs of 0.5 and 0.25 for recruits and spawners, respectively, the expected correlation is −0.44.

② This sample correlation is significant at the 0.05 level (n>20), even if there was no dome-shaped relationship between spawners and recruits.

③ A test of significance of the declining right-hand limb of spawner-recruit models with the Ricker model using correlation or regression techniques can lead to erroneous conclusions.

Method 2, plotting ln R values against ln SSB values, also has a serious problem. Sakuramoto and Suzuki (2012) conducted detailed simulations to investigate this matter.

The simulations tested whether or not the true SRR model, which was assumed in the simulation, was correctly selected under the conditions in which observed and/or process errors were incorporated in R and SSB. Here, ‘process errors’ denotes environmental changes.

Three SRR models were assumed in the simulations:

(a) The Ricker or Beverton and Holt (B-H) model, which was representative of density-dependent SRR models.

(b) The proportional model, which is representative of the density-independent SRR model.

I present only the results of the simulations here. Sakuramoto and Suzuki (2012) found the following:

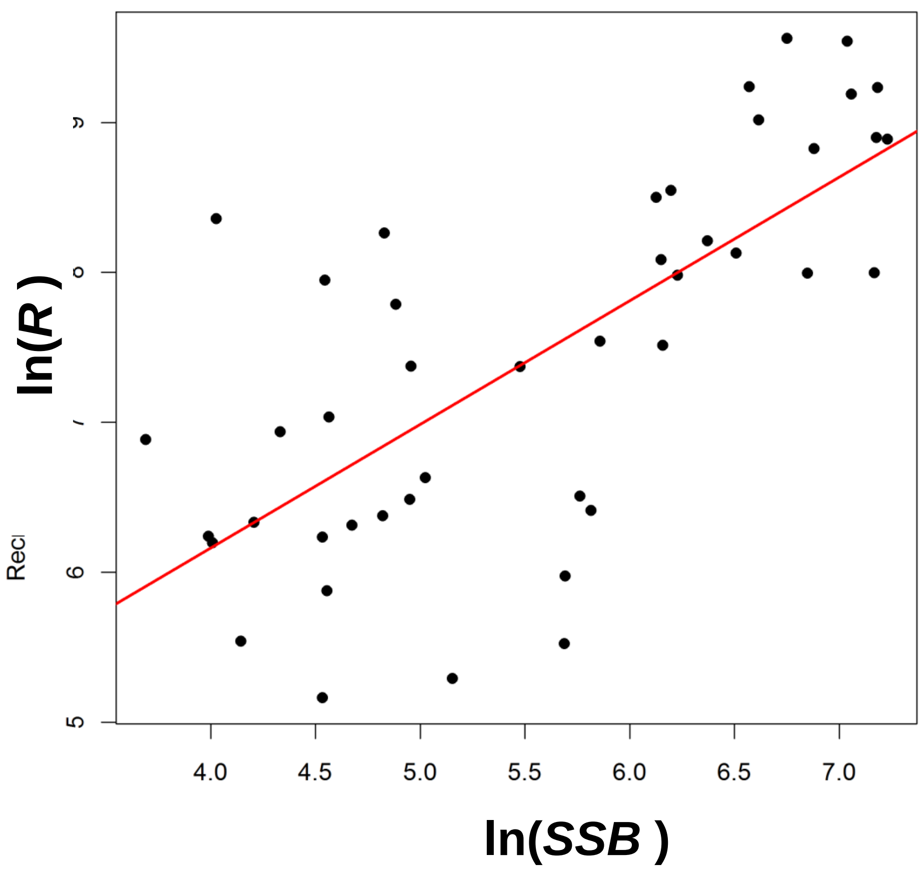
(1) Even in the case in which a proportional model was set as a true SRR model, the Ricker or B-H model was often selected as an optimal model in response to observation and/or process errors. That is, the minimum AIC value does not always select the true model.

The interesting point derived from this simulation was that the inverse phenomenon seldom occurred. That is,

(2) If the B-H or Ricker model was set as the true SRR model, the proportional model was seldom selected as the optimal model in response to observation and/or process errors.

This Figure shows SRR for chub mackerel (*Scomber japonicus*) in the waters off northeastern Japan (Japanese Fisheries Agency, 2014)

$$\ln(R) = \ln(a) + \ln(SSB) \rightarrow R = aSSB$$



The slope of the regression line was 0.824 and the 95% confidence intervals were (0.570, 1.077).

That is, this slope was not significantly different from unity, and no DDE was detected in the SRR.

As the simulation showed, the slope seldom became unity in response to observation and/or process errors.

This indicates that the proportional model was appropriate for this stock.

However, these points had been reported over 40 years ago by Maelezer (1970), Kuno (1971), and Ito (1972).

For instance, Kuno (1971) noted that:

(1) In the tests to detect density-dependence by using regression analysis, the error consistently acts as if it were a density-dependent factor.

(2) Under the effect of sampling error, the slope *b* for the regression of log N_{t+1} on log N_t is expected to become <1 even where there is no density-dependent factor at all.

1. Maelezer, D.A., *Ecol.* 51, 810-822 (1970).
2. Kuno, E. *Res. Popul. Ecol.* XIII, 28-45 (1971).
3. Ito, Y. *Oecol.* 6, XI , 10, 347-372 (1972).

II. Why we have not noticed the misunderstanding for a concept of stock-recruitment relationship (SRR)?

III. Application of the new concept of the SRR for the Pacific stock of Japanese sardines

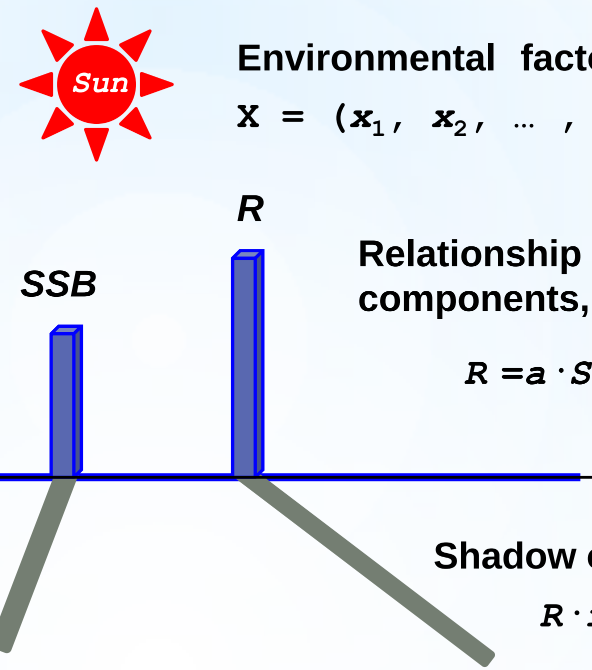
IV. Preliminary analysis of the fluctuation mechanism in the recruitment of the Pacific stock of bluefin tuna

As I showed above, Methods 1 and 2 are both problematic, and the probability that a DDE detected using these two methods was wrong must be extremely high.

My question concerns why the warnings about this from over 40 years ago were ignored. It is not clear why biologists have neglected the warnings, and why they have continued to believe in the existence of a DDE.

Why have biologists not noticed this misunderstanding for so long? I have considered the possible reasons for several years, and I may have recently found the reason. I will try to explain the reason using the following metaphor.

Three components that determine the SRR



Environmental factors

$$X = (x_1, x_2, \ldots, x_k)$$

R

SSB

Relationship between two components, *R* and *SSB*

$$R = a \cdot SSB$$

Shadow of SSB

$$SSB \cdot g(X)$$

Shadow of R

$$R \cdot f(X)$$

Observed data of SSB

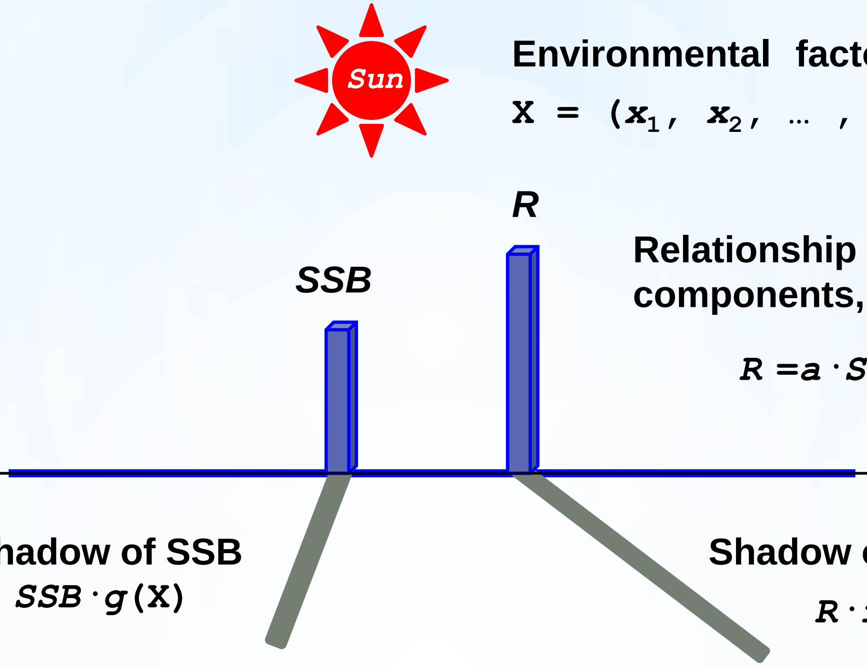
$$SSB_{obs} = SSB \cdot g(X) e^{\varepsilon}$$

Observed data of R

$$R_{obs} = R \cdot f(X) e^{\lambda}$$

Shadows with observation errors are observed as SRR data

Three components that determine SRR



Environmental factors

$X = (x_1, x_2, \ldots, x_k)$

Relationship between two components, *R* and *SSB*

$R = a \cdot SSB$

Shadow of SSB

$SSB \cdot g(X)$

Shadow of R

$R \cdot f(X)$

Observed data of SSB

$SSB_{obs} = SSB \cdot g(X) e^{\varepsilon}$

Observed data of R

$R_{obs} = R \cdot f(X) e^{\lambda}$

Shadows with observation errors are observed as SRR data

Current SRR model:
$R_{obs} = \psi(SSB_{obs})$

→

Proposed SRR model:
$R_{obs} = a \cdot SSB_{obs} \cdot \varphi(X)$

II. Why we have not noticed the misunderstanding of the concept of a stock-recruitment relationship (SRR) ?

III. Recruitment forecasting model for the Pacific stock of Japanese sardines that does not assume a density-dependent effect

IV. Preliminary analysis for the fluctuation of recruitment in the Pacific stock of bluefin tuna

* When I adapted this new concept of SRR for the Pacific stock of Japanese sardine, I used the Arctic oscillation in February of year t ($AO_{t,2}$) and SST in the Kuroshio extension area (30-35° N – 145-180° E) in February of year t ($KEST_{t,2}$) referred to by Sakuramoto et.al. (2010). The recruitment forecasting model proposed is as follows (Sakuramoto, 2013):

$$R_{t,obs} = a \cdot S_{t,obs} \cdot F\left(AO_{t,2},\ KEST_{t,2}\right)$$

R_t : Recruitment in year *t*

S_t : Spawning stock biomass in year *t*

I will show the results of a simulation when the recruitments are forecasted using the above SRR model.

This matrix explains the case when simulation is conducted from 2001

Year

Age	2000	2001	2002	2003	2004	2005
0	$R_{0,2000}$					
1	1	$N_{1,2001}$				
2	2	2	$N_{2,2002}$			
3	3	3	3	$N_{3,2003}$		
4	4	4	4	4	$N_{4,2004}$	
5	5	5	5	5	5	$N_{5,2005}$

Estimated by SRR model

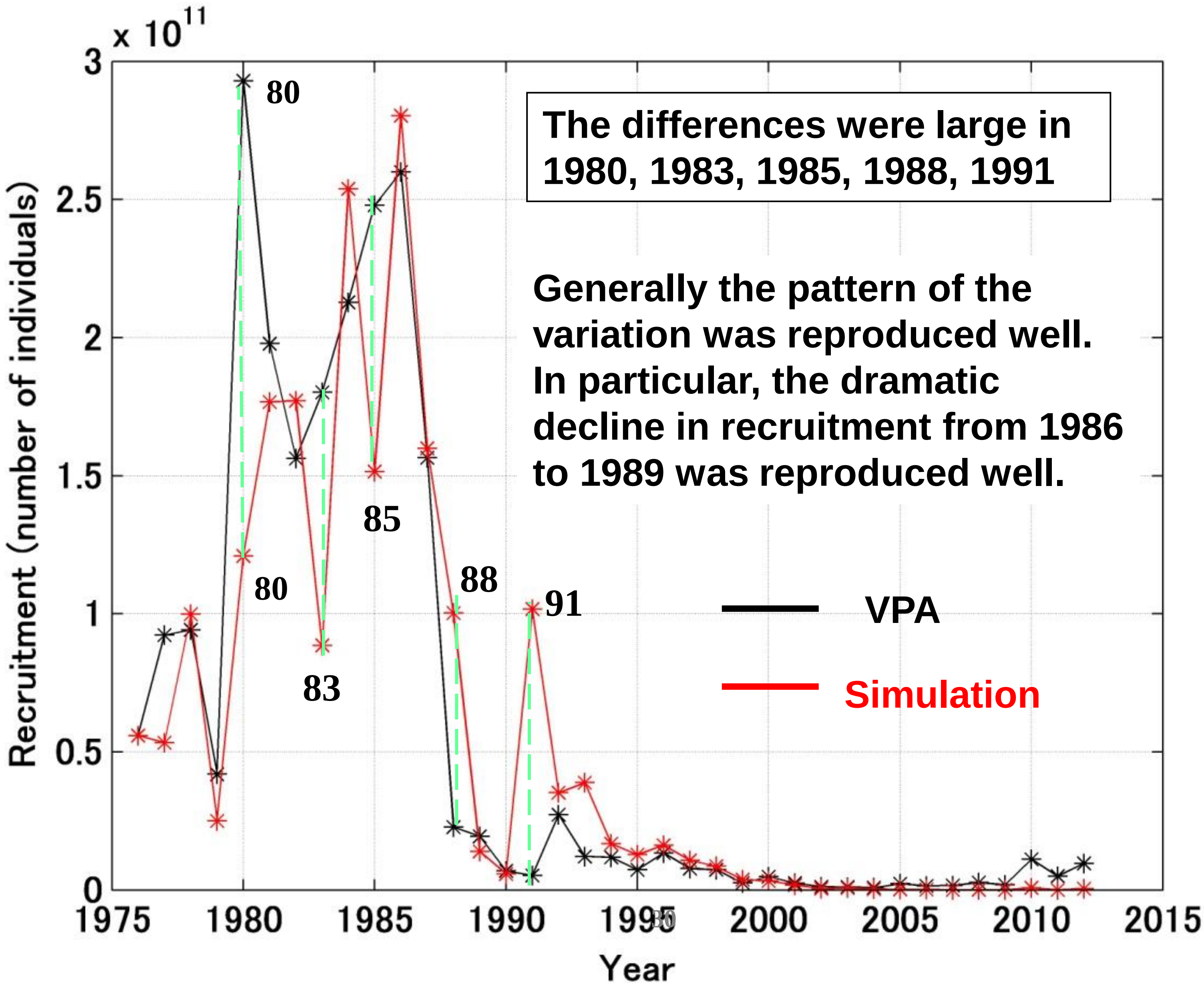
SSB

Initial values given

$AO_{t,2}$, $KEST_{t,2}$, M (natural mortality coefficient), m_{at} (maturity rate)

F_{at} (fishing mortality coefficients estimated by VPA) are given.

Recruitment observed and forecasted



The differences were large in 1980, 1983, 1985, 1988, 1991

Generally the pattern of the variation was reproduced well. In particular, the dramatic decline in recruitment from 1986 to 1989 was reproduced well.

* Conclusion of the above discussions

(1) The commonly used methods to detect a DDE have a fatal defect. Almost all studies detecting DDEs are controversial.

(2) As long as a 2-dimensional SRR model is used, the discussion does not make sense. We should discuss the SRR by using a 3- or more than 3-dimensional model.

(3) For the Japanese sardine, recruitment can be reproduced using more than 3-dimensional model that does not assume a DDE. The model is expressed as follows:

$$R_{t,obs} = a \cdot SSB_{t,obs} \cdot F\,(\mathrm{KEST}_{t,2}, \mathrm{AO}_{t,2})$$

That is, the environmental factors play a major role while the essential relationship between R and SSB is proportional.

II. Why we have not noticed the misunderstanding of the concept of a stock-recruitment relationship (SRR) ?

III. Recruitment forecasting model for the Pacific stock of Japanese sardines that does not assume a density-dependent effect

IV. Preliminary analysis for the fluctuation of recruitment in the Pacific stock of bluefin tuna

* For the case of the Pacific stock of bluefin tuna, I tried to adapt the same concept of the SRR model used for Japanese sardines; that is,

$$R_{t,obs} = a \cdot S_{t,obs} \cdot F(environmental\ \ factors)$$

In accord with the case of sardines, I checked three indices as environmental factors:

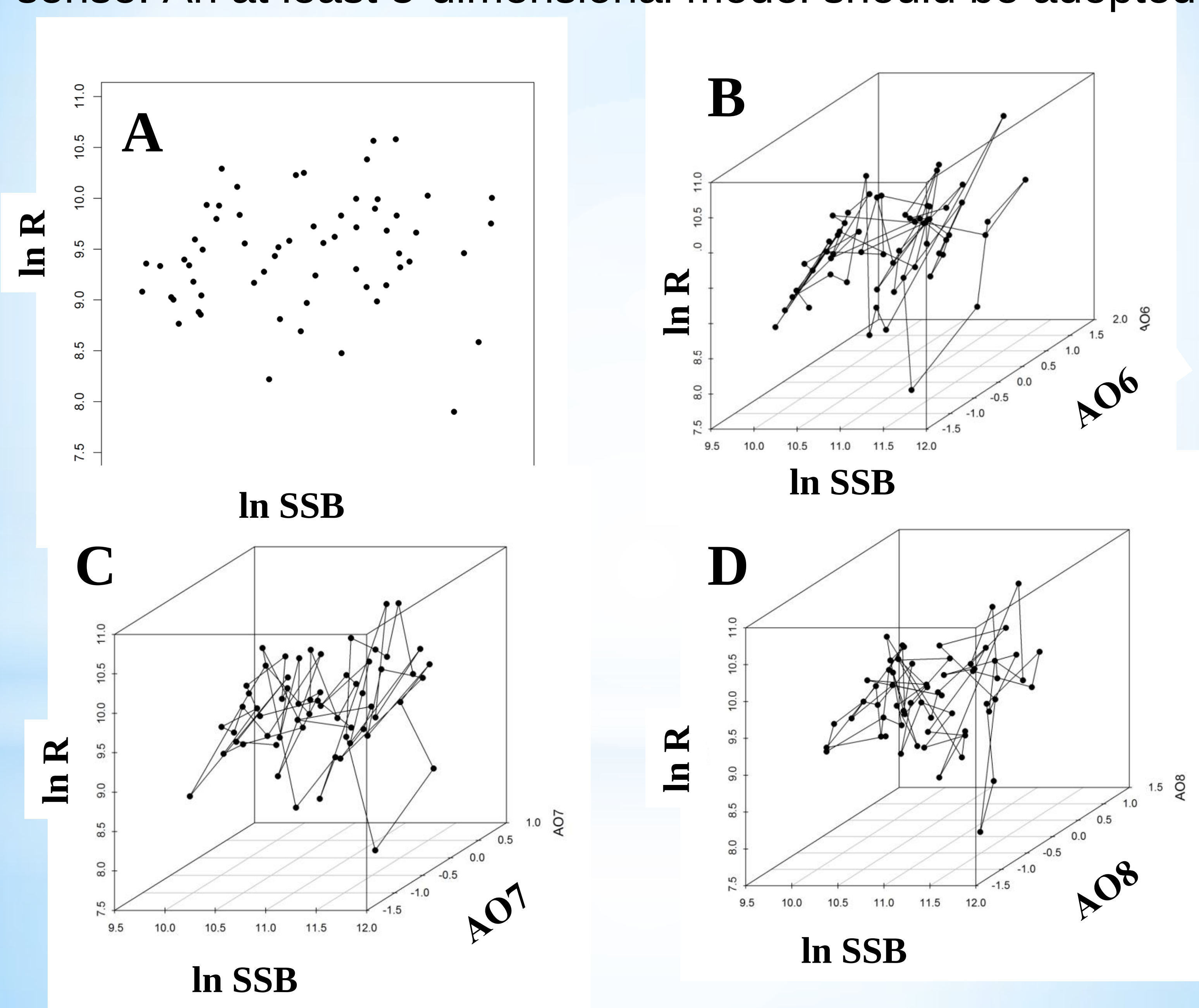
(1) Arctic oscillation in month *m* of year *t* ($AO_{t,\ m}$),

(2) Pacific decadal oscillation in month *m* of year *t* (PDO_t),

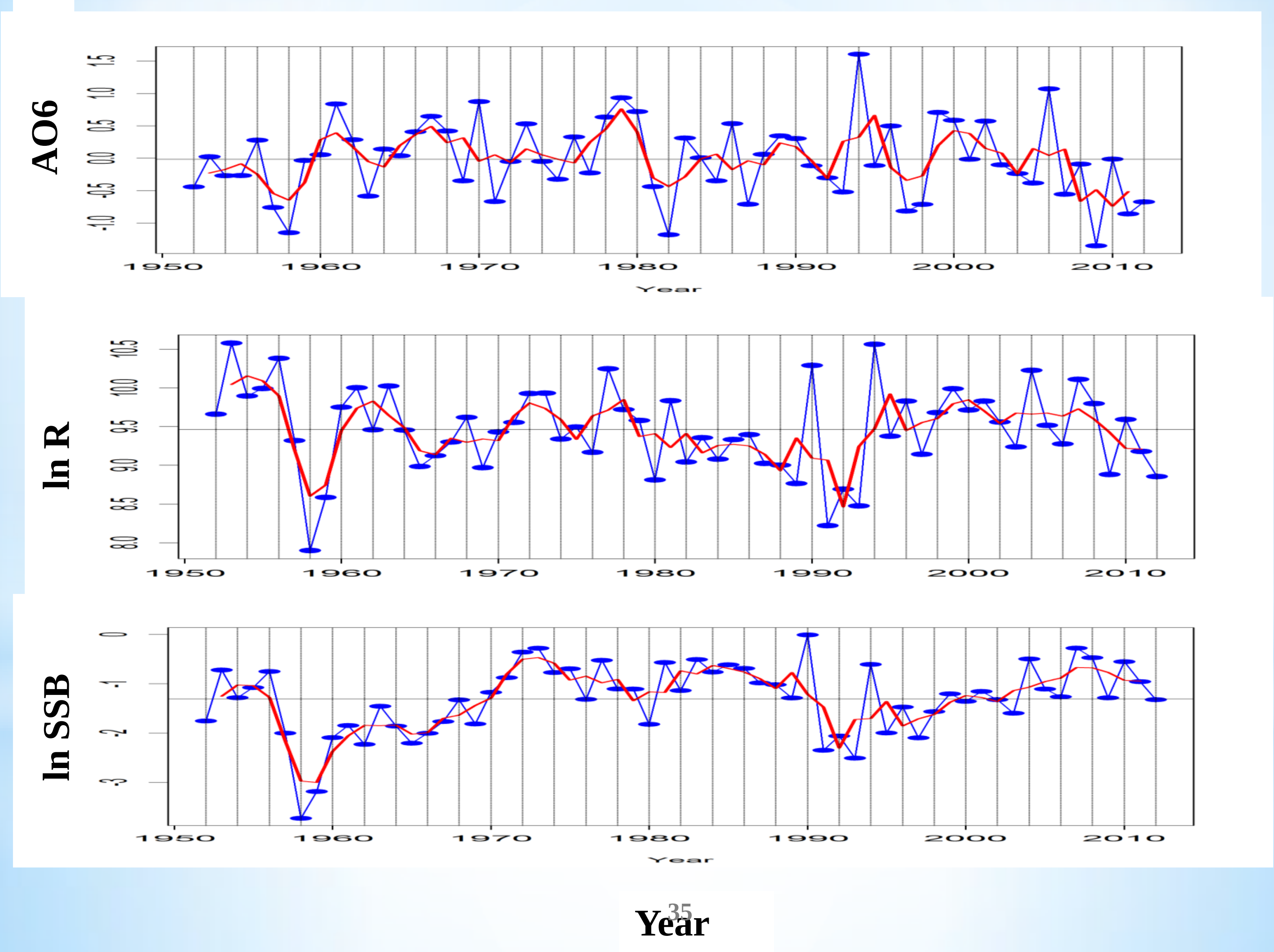
(3) Sea surface temperatures in the western Pacific Ocean in month *m* of year *t* ($SST_{t,\ m}$).

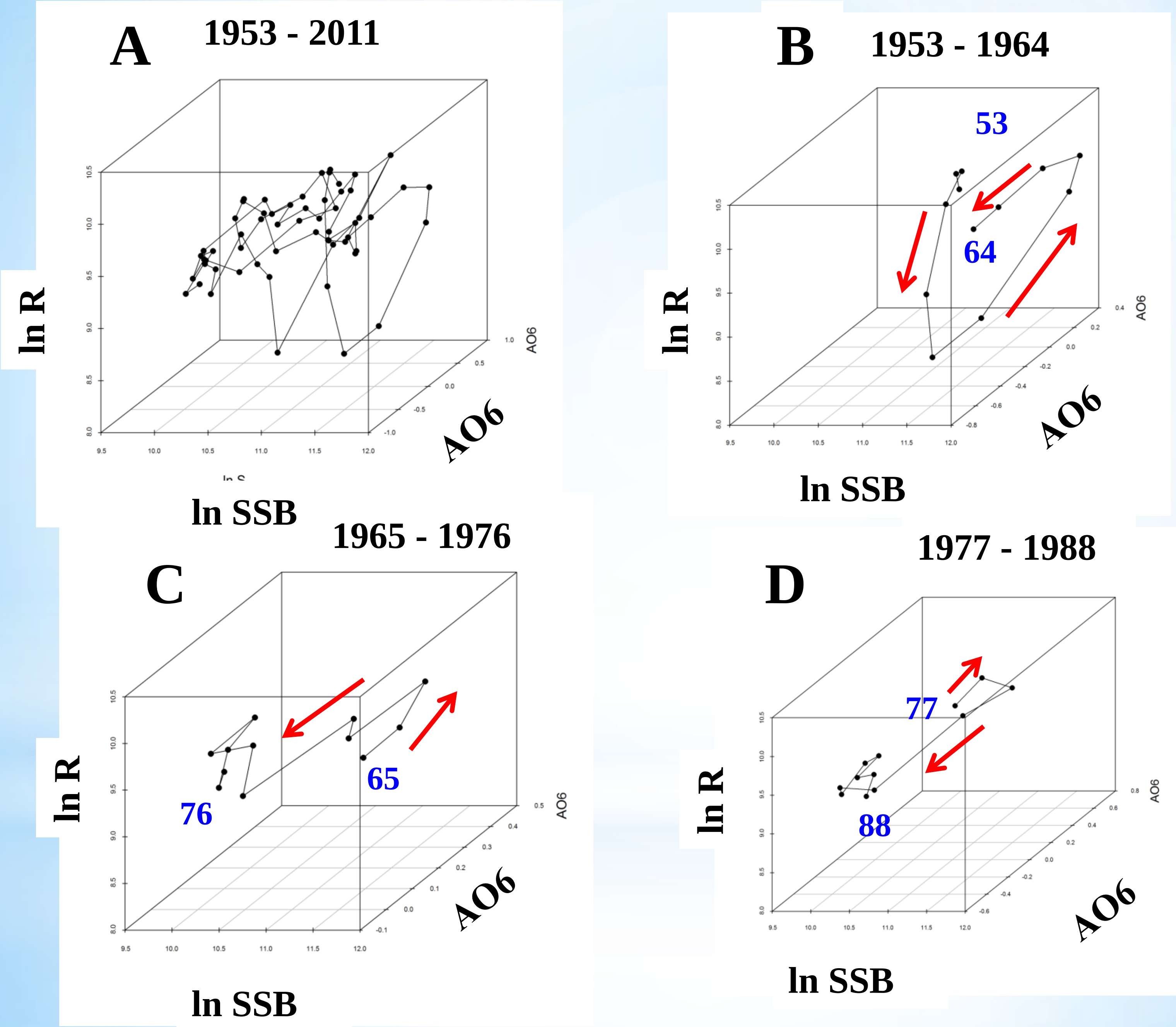
The last environmental factor will be explained later.

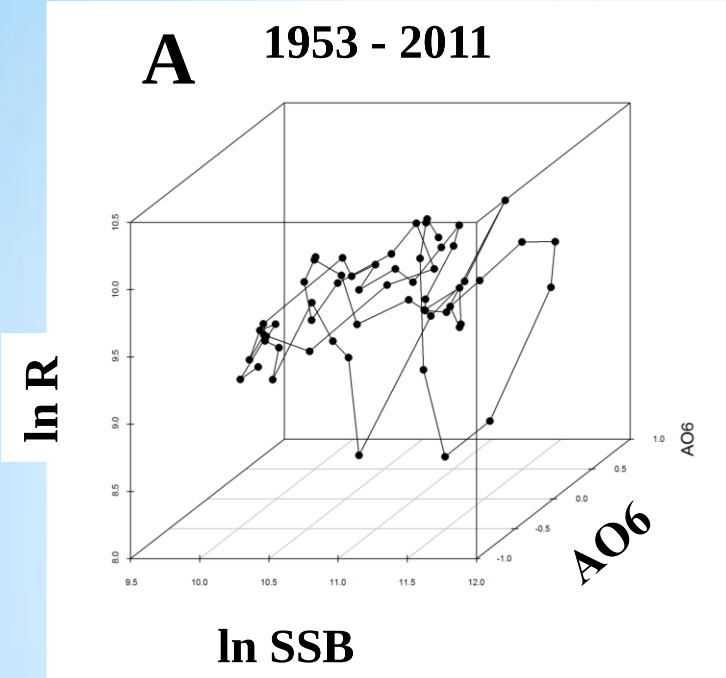
As I noted before, the 2-dimensional model never made sense. An at least 3-dimensional model should be adopted.

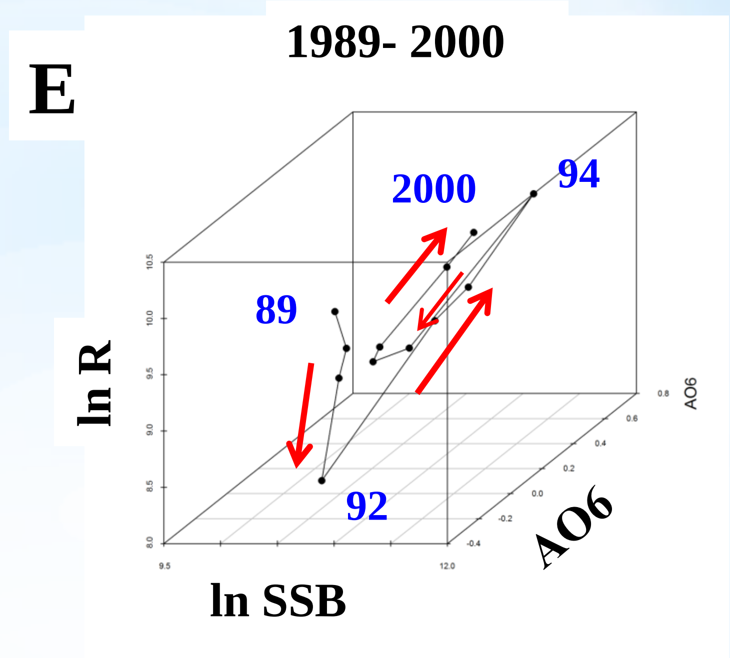


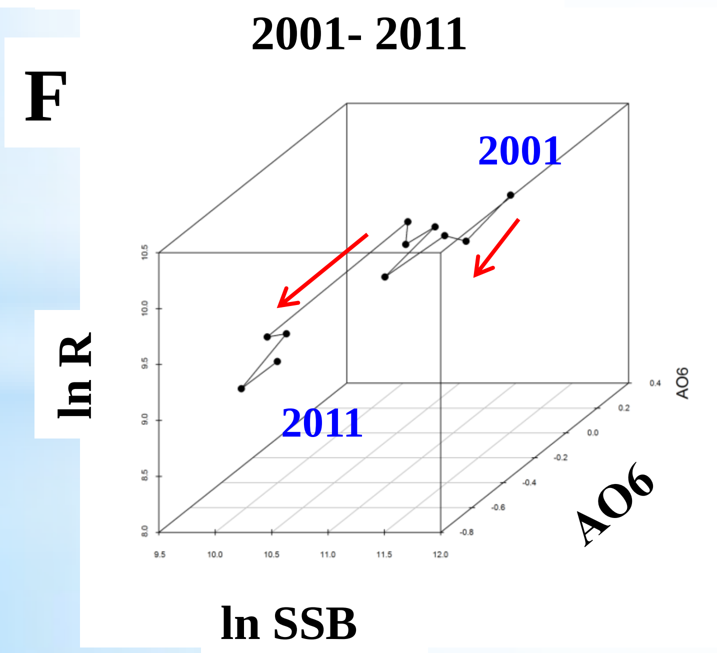
These figures show the trajectories of AO, ln R and ln SSB in June.
The red broken lines show the 3-year moving averages.




A
1953 - 2011
ln R
ln SSB
AO6
B
1953 - 1964
53
64
ln R
ln SSB
AO6
C
1965 - 1976
65
76
ln R
ln SSB
AO6
D
1977 - 1988
77
88
ln R
ln SSB
AO6







In the other periods, the tendencies were the same.

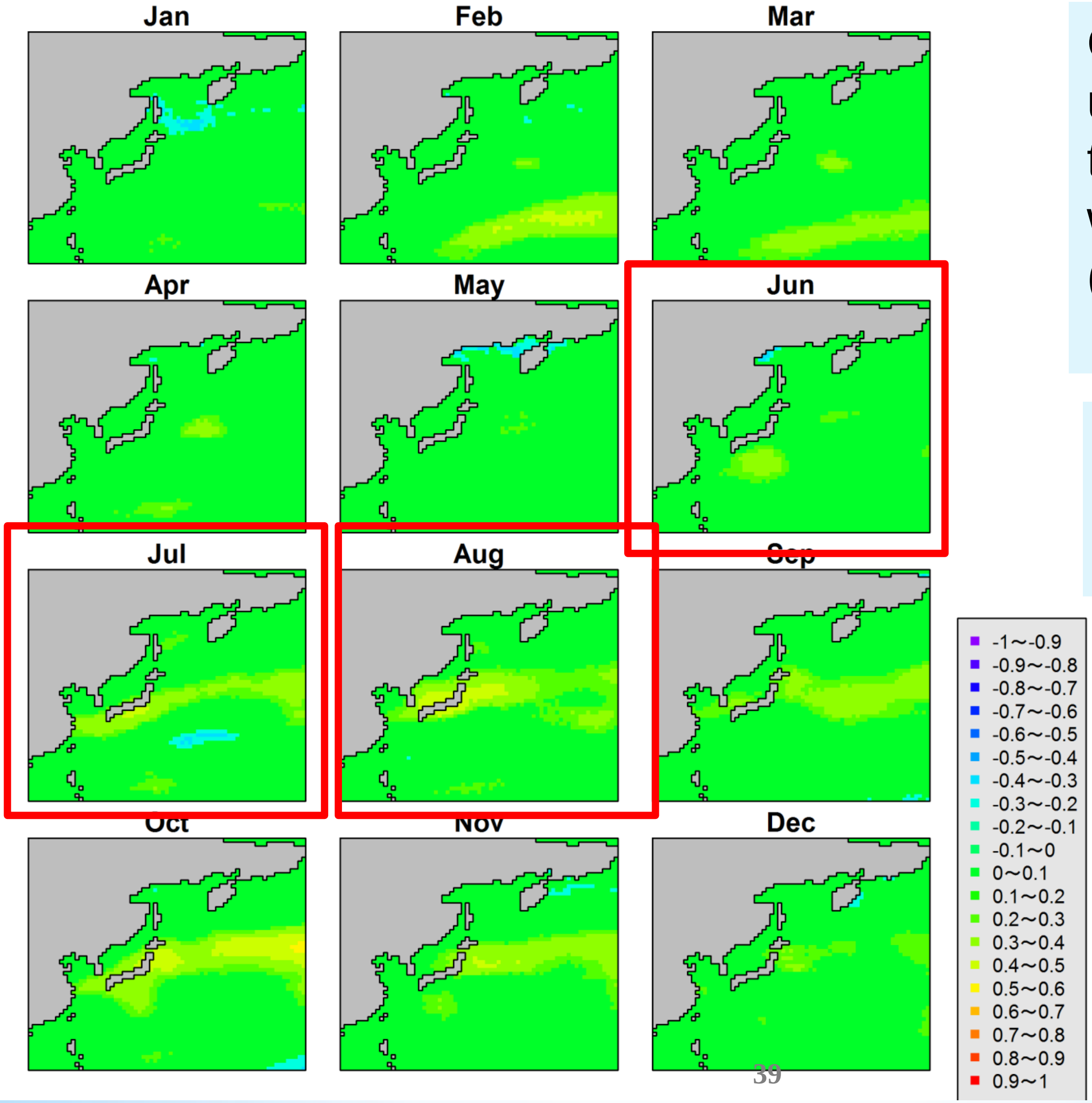
That is, according to decreasing AO in June, ln R also decreased, and vice versa.

Next, let’s explain how to calculate the sea surface temperatures in the western Pacific Ocean in month *m* of year *t* ($SST_{m, t}$).

We used the sea surface temperatures in the areas of 10–70° N to 110–170° E (the Japan Meteorological Agency).

The correlation coefficient between R in year *t* and the SST in month *m* of year *t* was calculated by every 0.1-degree square, and each unit area was painted a different color depending on the strength of the correlation coefficient (Sakuramoto and Matsubara, unpubl.).

Correlation coefficients between R_t and $SST_{m,t}$

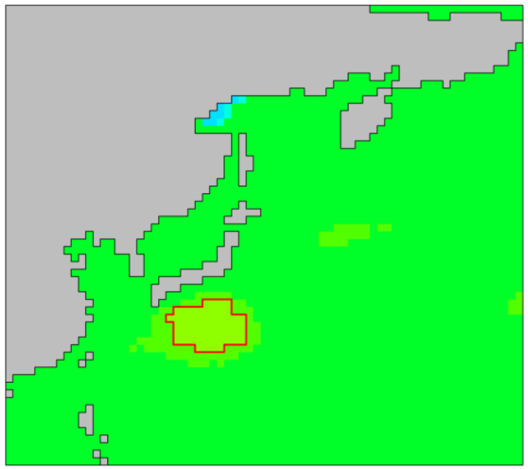


Green denotes the unit area in which the cor. coeff. (CC) was not significant (5% significant level).

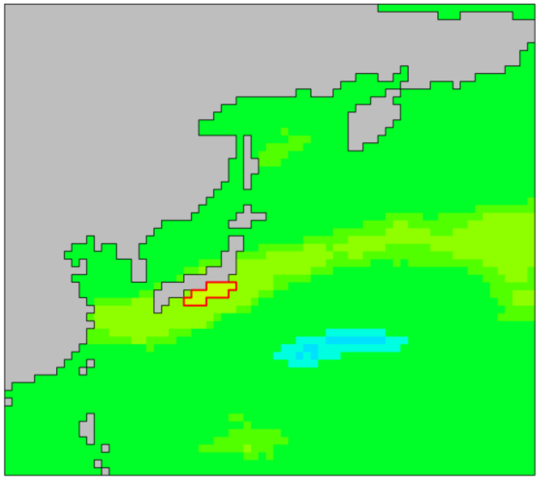
Warm colors indicate that the CC was significantly positive.

Cold colors indicate that the CC was significantly negative.

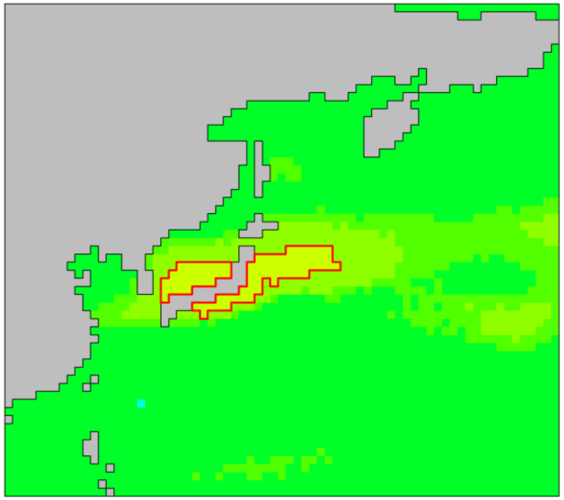
Jun



Jul.

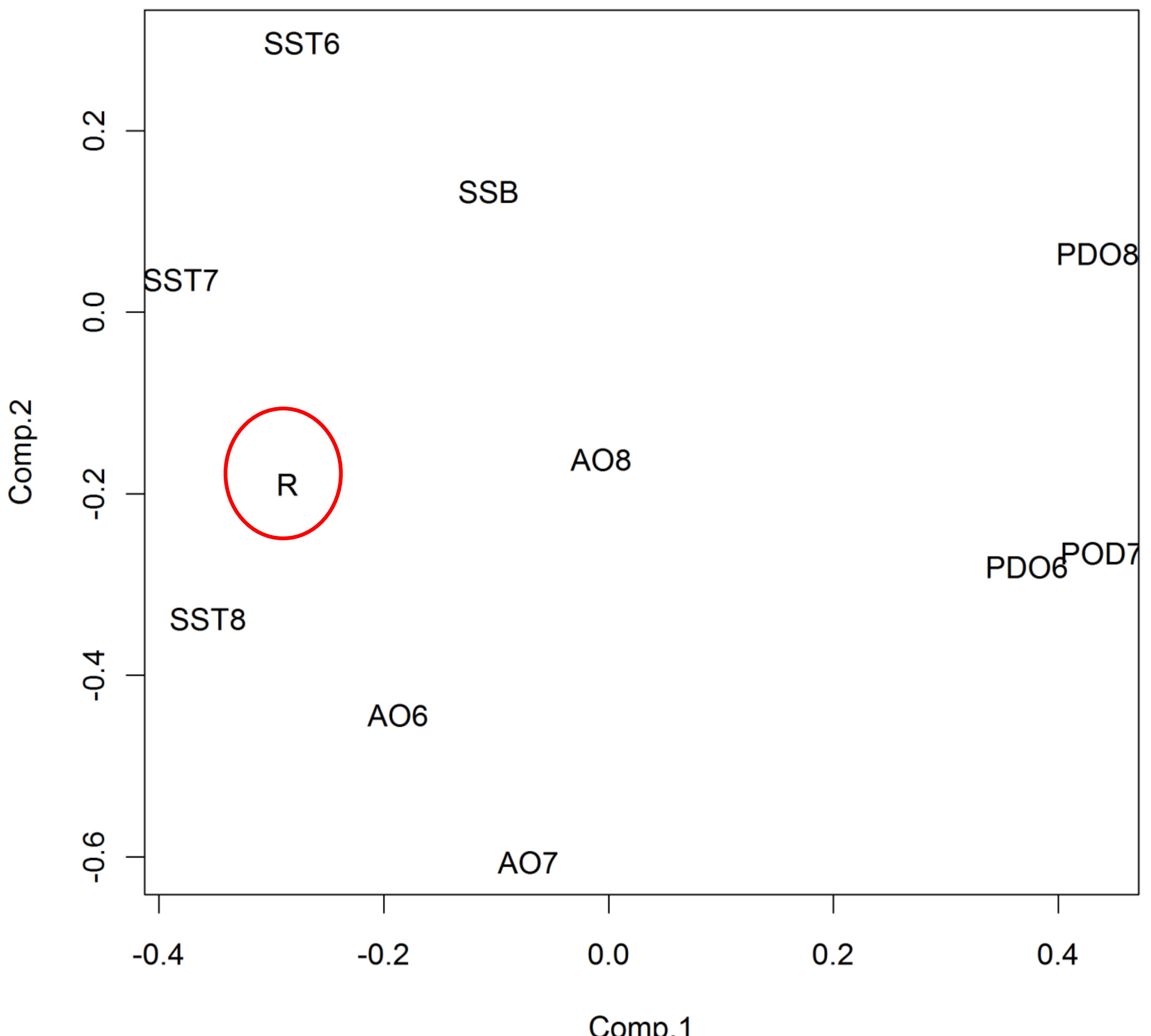


Aug.



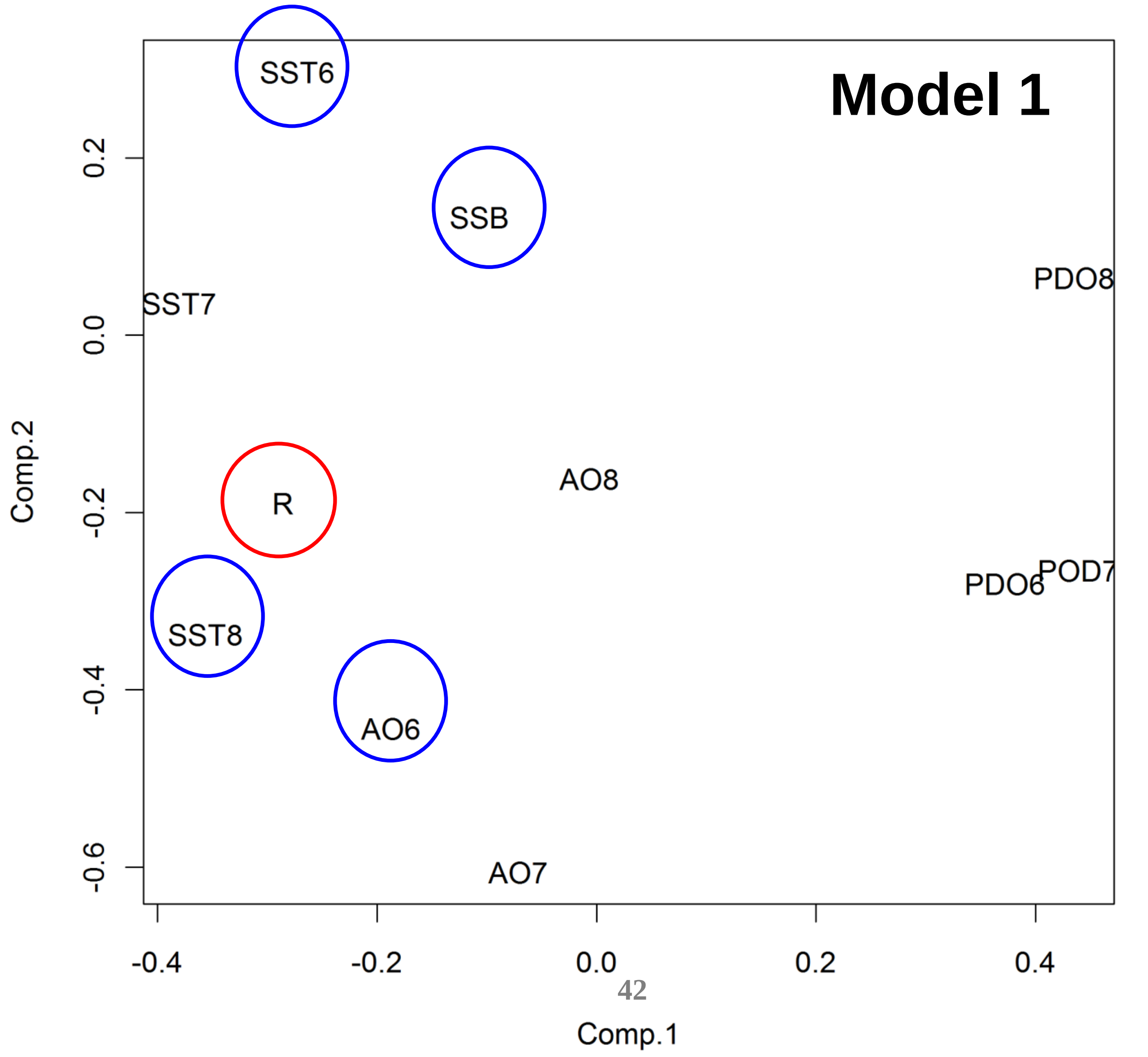
The units in which the CC were >0.4 are surrounded by a red line, and I calculated the average sea surface temperature by year. Hereafter, I refer to these surface temperatures as $SST_{t,\,6}$, $SST_{t,\,7}$ or $SST_{t,\,8}$, respectively.

Results of the principle component analysis

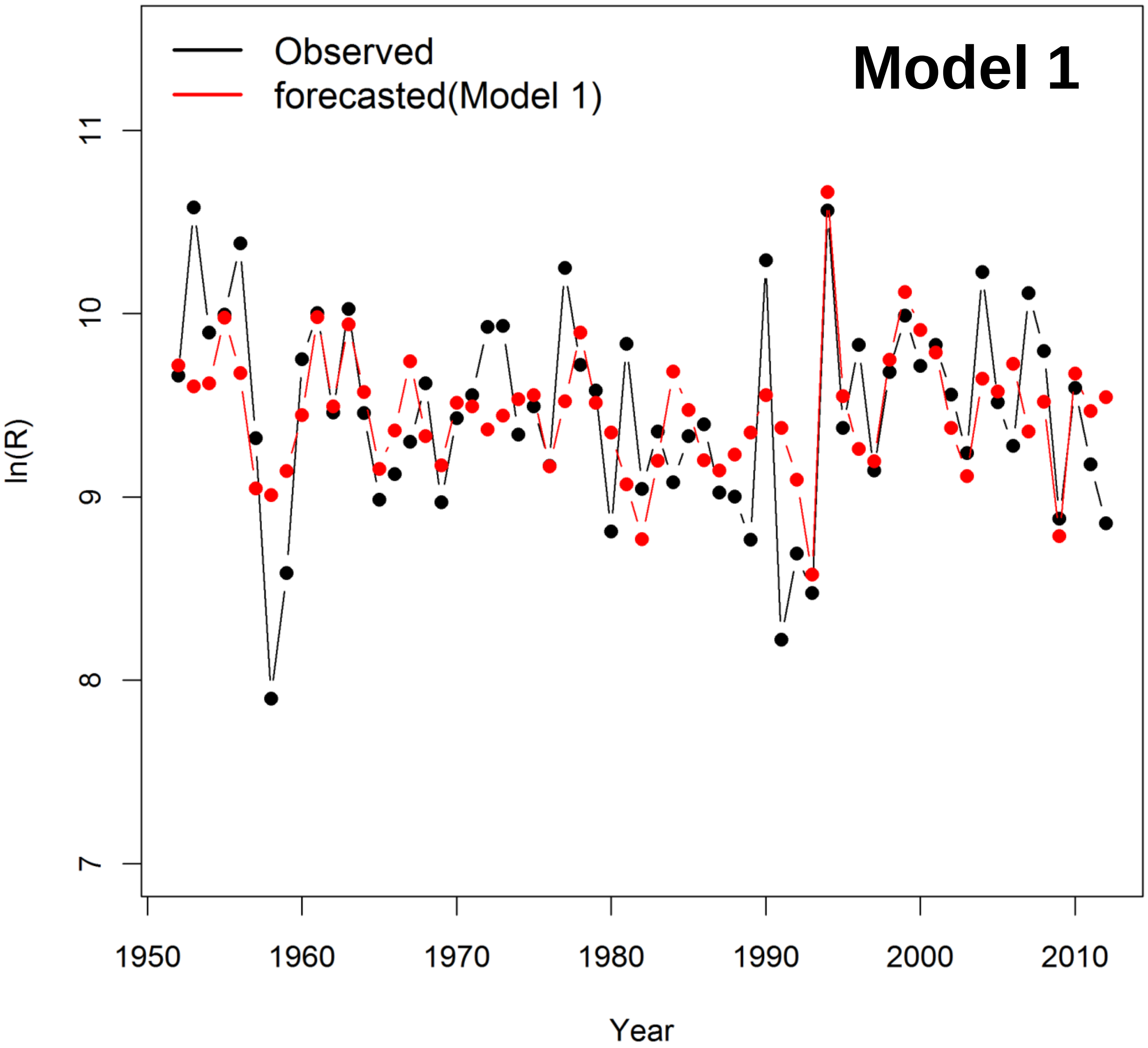


The variables that were used in the model in which the SS value was minimum

$$Sum\ of\ square\,(SS) = \sum \left(\ln R_{cal} - \ln R_{obs}\right)^2$$

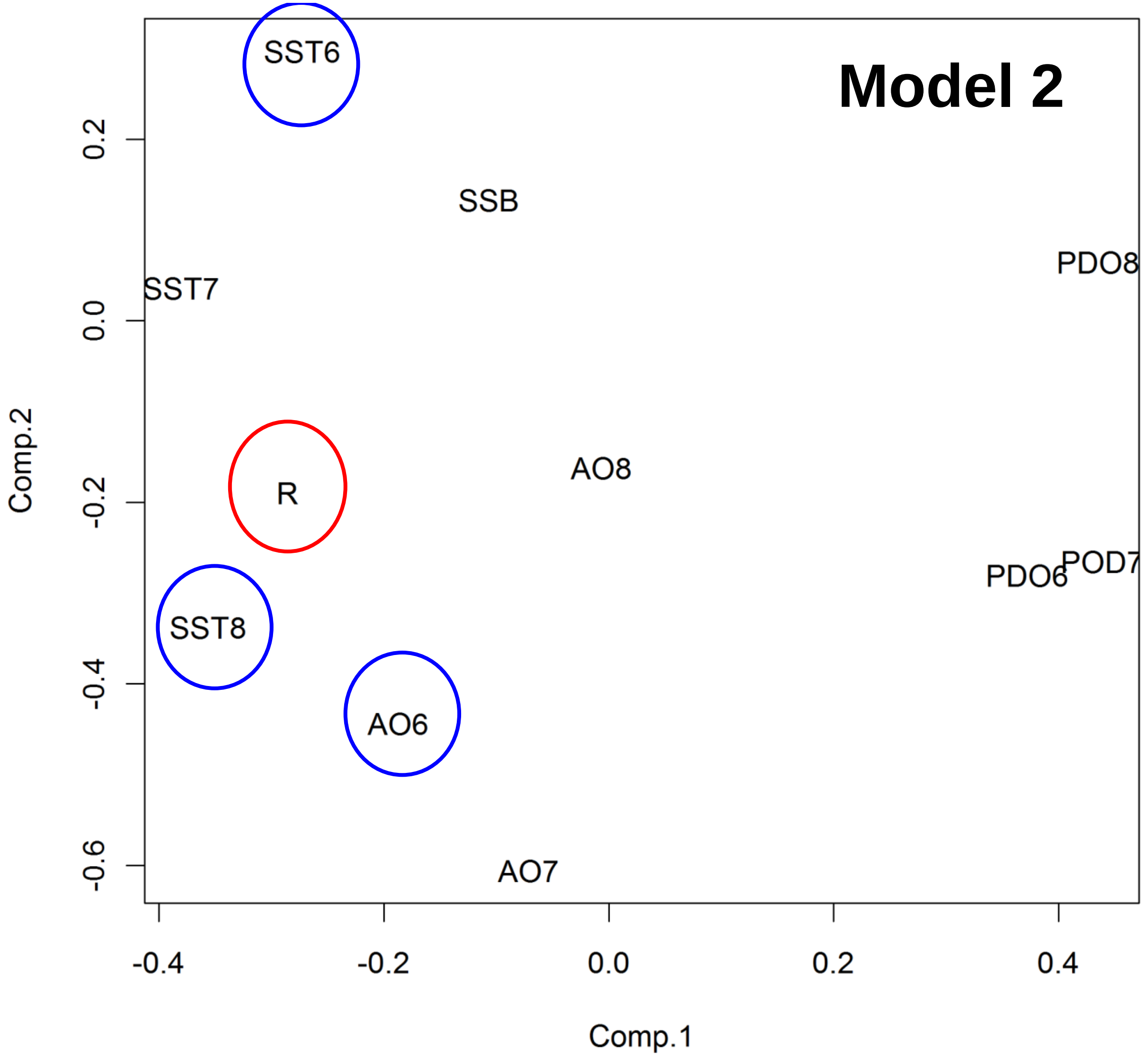


Sum of squares minimum SRR model

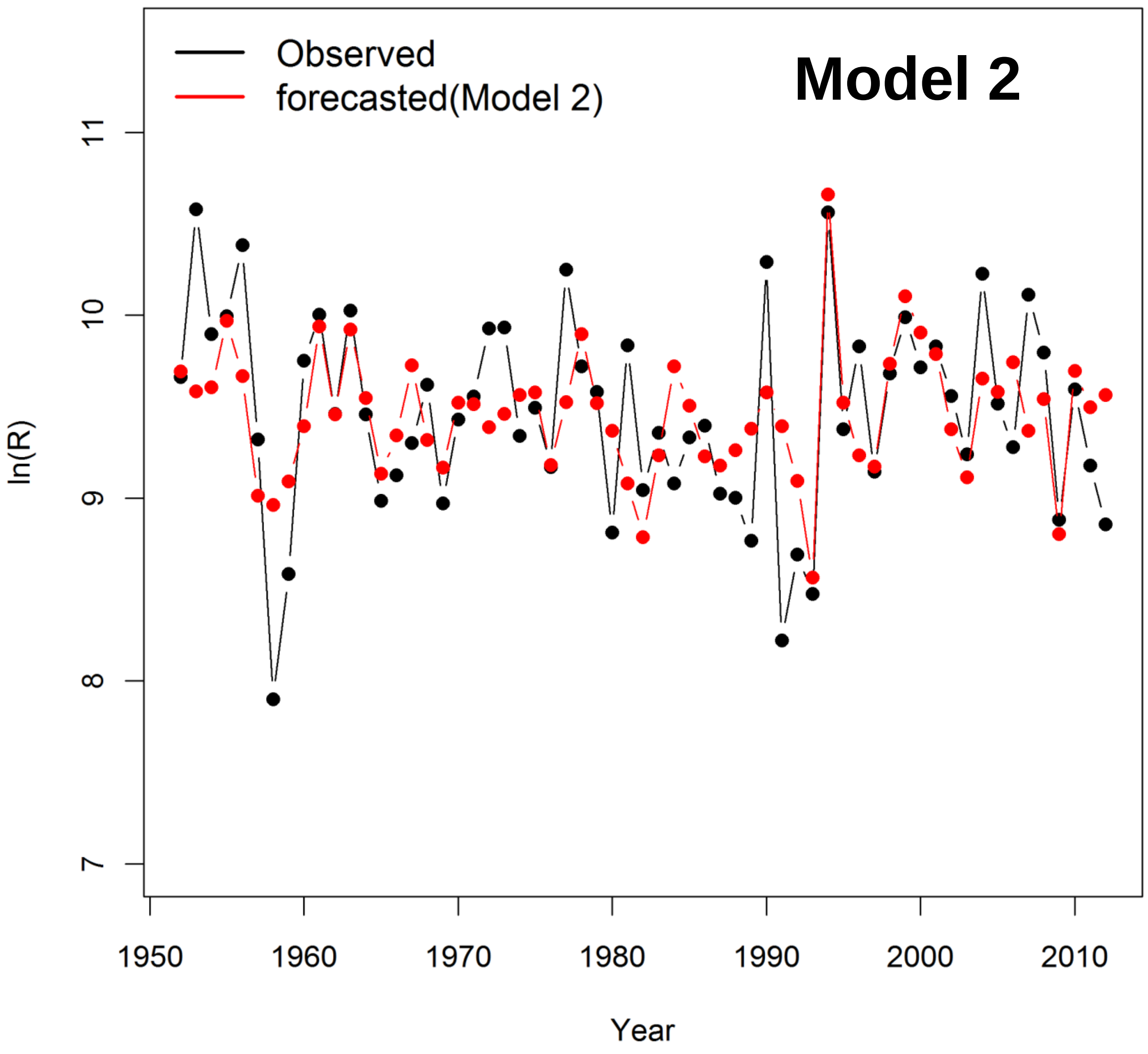


$$\ln R_t = -4.86 + 0.044 \ln SSB_t + 0.143\mathrm{AO}_{t,6} + 0.246\,\mathrm{SST}_{t,6} + 0.307\mathrm{SST}_{t,8}$$

The variables that were used in the model for which the AIC was minimum

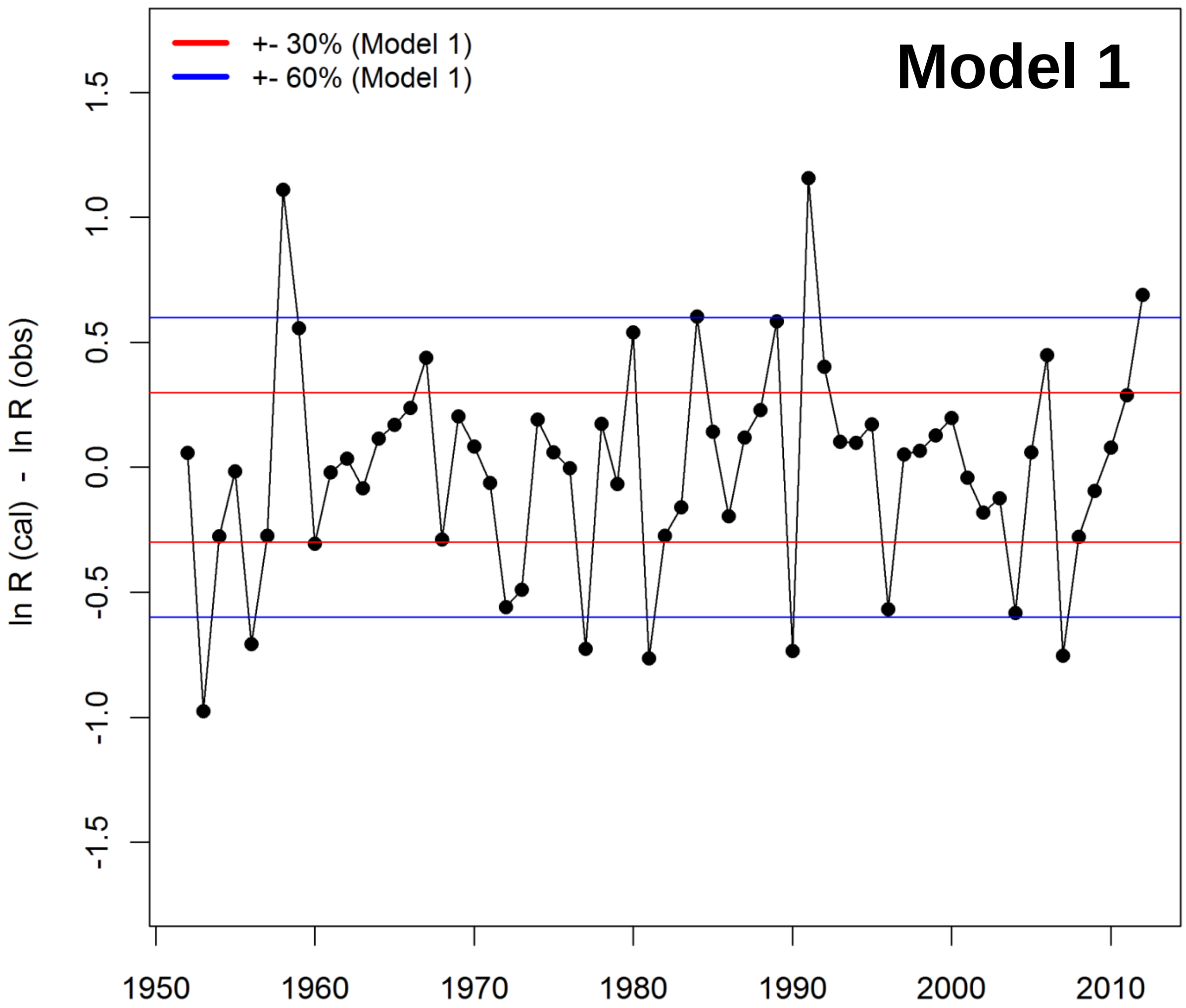


AIC minimum SRR model



$$ln\ R_t = -4.56 + 0.147AO_{t,6} + 0.256\ SST_{t,6} + 0.307SST_{t,8}$$

The broken lines show the precision



Number of years within red lines = 41 years (61) (72%)

Number of years within blue lines = 52 years (61) (85%)

$$\text{Precision} = [(\ln\ R_{cal} - \ln\ R_{obs}) / \ln\ R_{obs}\ ] \times 100$$

* Results of the preliminary analysis of the fluctuation in recruitment for the Pacific stock of bluefin tuna

Sum of square (SS) minimum model (Model 1)

$R_t = a \cdot SSB_t \cdot \varphi\,(\mathrm{AO}_{t,\,6},\ \mathrm{SST}_{t,\,6},\ \mathrm{SST}_{t,\,8})$ SS = 10.93, AIC = - 94.87

AIC minimum model (Model 2)

$R_t = c \cdot g\,(\mathrm{AO}_{t,\,6},\ \mathrm{SST}_{t,\,6},\ \mathrm{SST}_{t,\,8})$ SS = 10.96, AIC = - 96.69

The difference in SS or AIC between Models 1 and 2 was not large. The difference in AIC was less than 2. As Sakuramoto and Suzuki (2012) noted that the minimum AIC value did not always select the true model.

Therefore, I would like to recommend to select Model 1. That is, the SRR model for bluefin tuna can be expressed by completely the same concept of that for Japanese sardines.

* **Regardless of whether Model 1 or 2 is used, the most important thing stressed here is environmental factors.**

  In other words, as long as we discuss the SRR with a 2-dimensional model, it does not make any sense.

  It also indicates that the MSY theory derived from the 2-dimensional SRR model does not make sense.

  Therefore, we should develop new procedures to manage fisheries resources that do not assume the MSY.

  Is this possible?

* **Yes, it is definitely possible.**
  I will provide two practical examples.

Example 1: Professor Tanaka and I proposed a management procedure for Baleen whales that does not assume any population model and does not assume a MSY.

The IWC/SC conducted an incredible number of simulations to determine the performance of the procedures. Five management procedures for Baleen whales were tested; three were model-based procedures and two were model-free procedures.

As Professors Butterworth and Punt know well, the performances of these five procedures were all good.

Example 2: The Japanese government has managed seven fisheries resources in Japanese coastal waters with TAC. However, recently the procedures that determine TACs never use the concept of MSY. They mainly use the concept of RPS and they have been used successfully to manage most of the resources.

The fact that the Japanese government does not use the concept of MSY and can manage the fisheries resources well provides a good example with which to develop a new management procedure that does not assume the MSY theory.

Conclusions:

(1) The MSY concept is incorrect.

(2) We should develop a new management procedure that does not assume the MSY theory.

(3) The origin of such procedures is already known. Therefore, the actions that we should take now are to discard the concept of MSY first, and then focus our efforts on the development of new management procedures that do not assume the MSY theory, in order to manage fisheries resources correctly.

Thank you for your attention.