2012 PICES Eel Workshop, Hiroshima, Japan

Spatial and temporal variations in the recruitment of Japanese eel (*A. japonica*) in Taiwan

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Outline of the presentation

1. Glass eel crisis for aquaculture in Taiwan

2. Basic biology of glass eel such as

2.1. Classification and identification

2.2. Species composition, why different between eastern and western coasts of Taiwan?

2.3. Upstream migration timing and environmental cues

3. Stock assessment by exploitation rate, YPR and SPR

4. Climate change effect on the recruitment of glass eel

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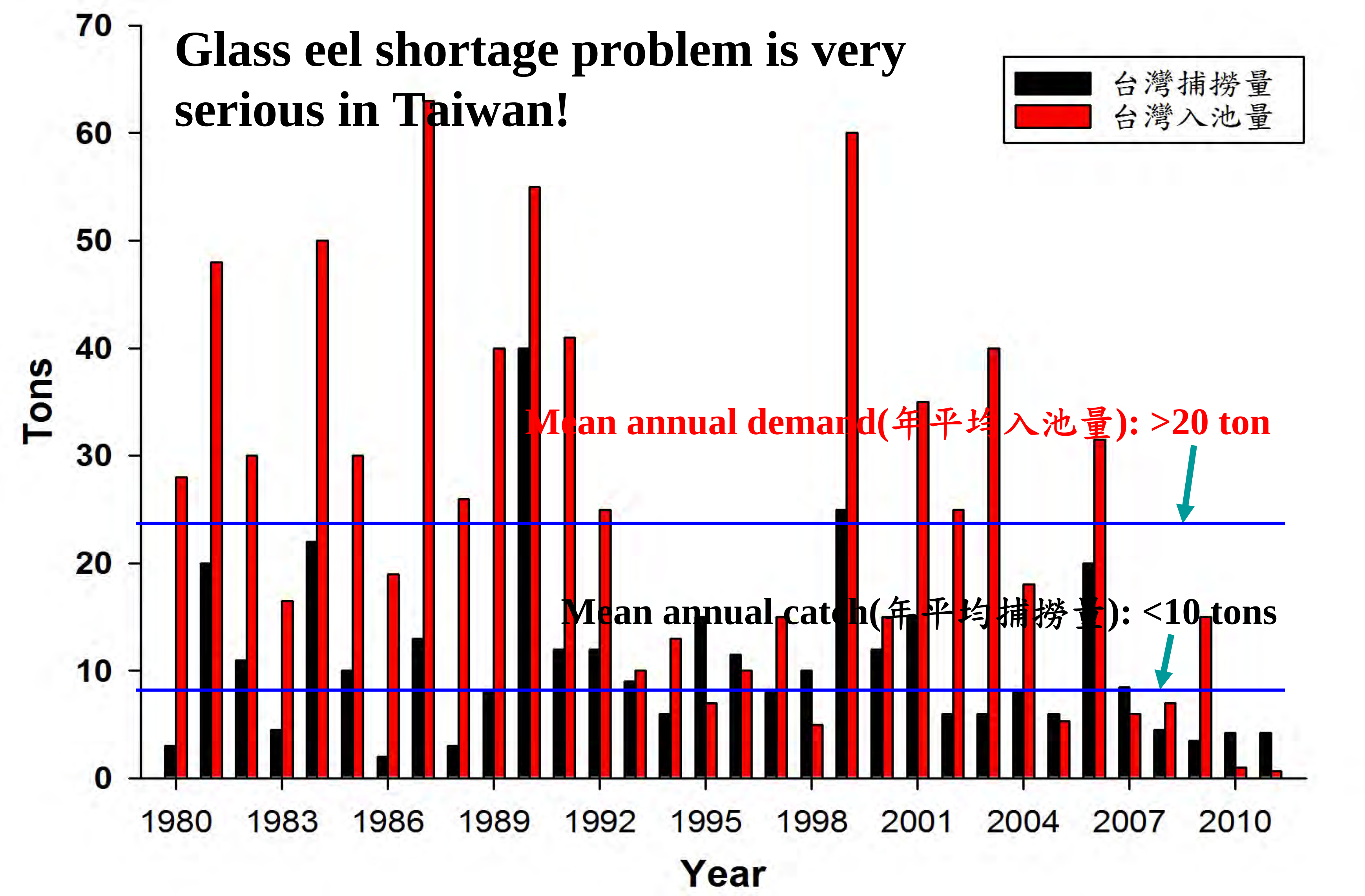
Fig.4-1. Eel culture production in Taiwan.

Supply of glass eel is lower than demand in Taiwan



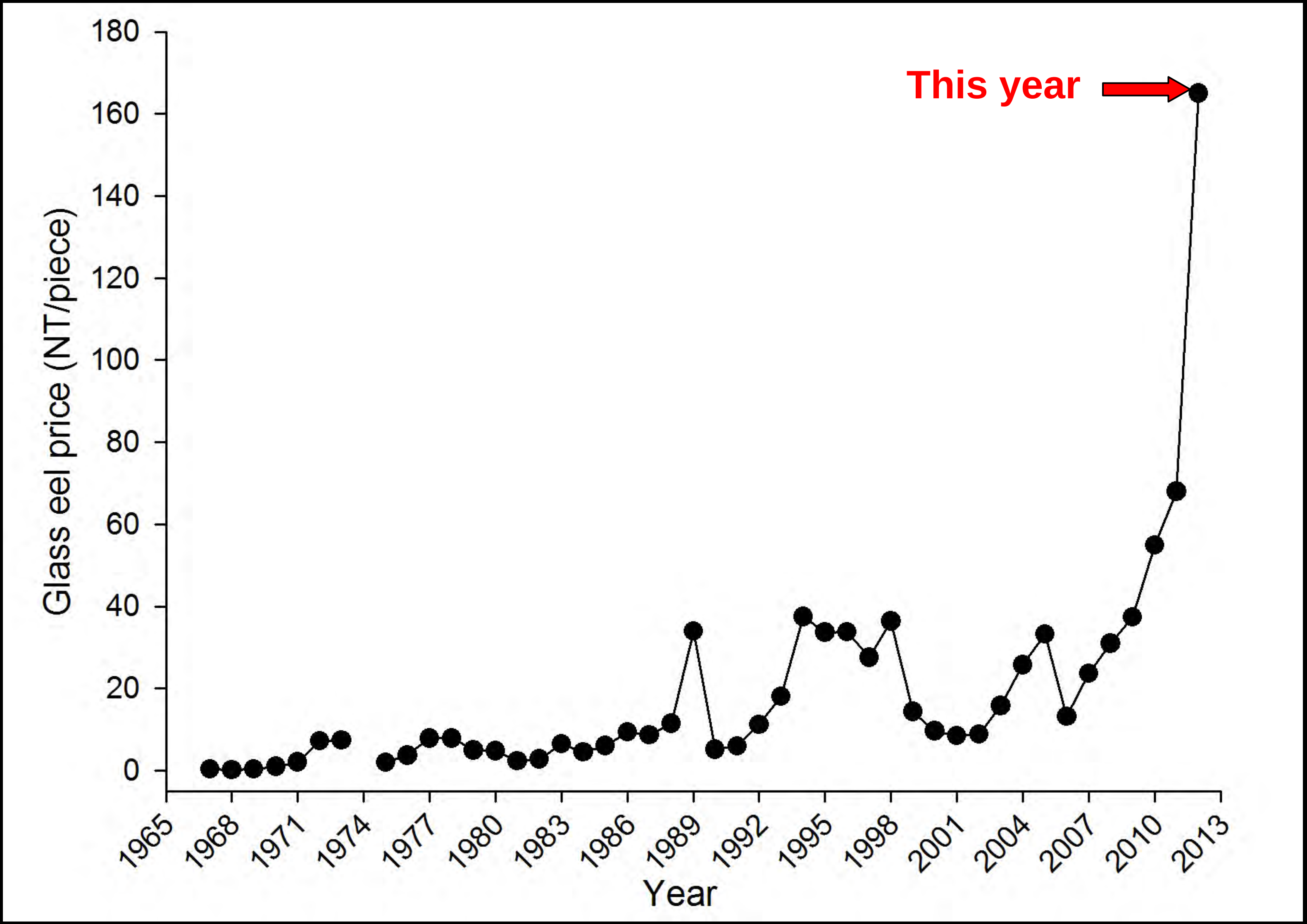
Statistics of the Glass eel for aquaculture among countries, 2006-2012,

Year	Taiwan		China		Japan		Korea		Total (tons)
	tons	%	tons	%	tons	%	tons	%	
2006	**31.5**	19.7	**77**	48.1	**29**	18.1	**22.1**	13.8	**160.1**
2007	**4**	5.8	**26**	37.9	**25.1**	36.6	**13.5**	19.7	**68.6**
2008	**7**	13.9	**10**	19.8	**22.5**	44.6	**11**	21.8	**50.5**
2009	**19**	18.3	**28**	28.1	**29.5**	35.2	**14.3**	18.3	**90.8**
2010	**1**	2.4	**10.5**	25.2	**19.5**	48.4	**10**	24	**41**
2011	**0.7**	2.0	**8**	22.9	**19.5**	55.7	**6.8**	19.4	**35**
2012*	**0.4-0.6**		**5-6**		**12-14**		**2-4**		**20-25**

*** : Prediction**

Taiwan is facing the eel aquaculture collapse in the recent 3 years because of the shortage of glass eel !!

Change of glass eel price in Taiwan



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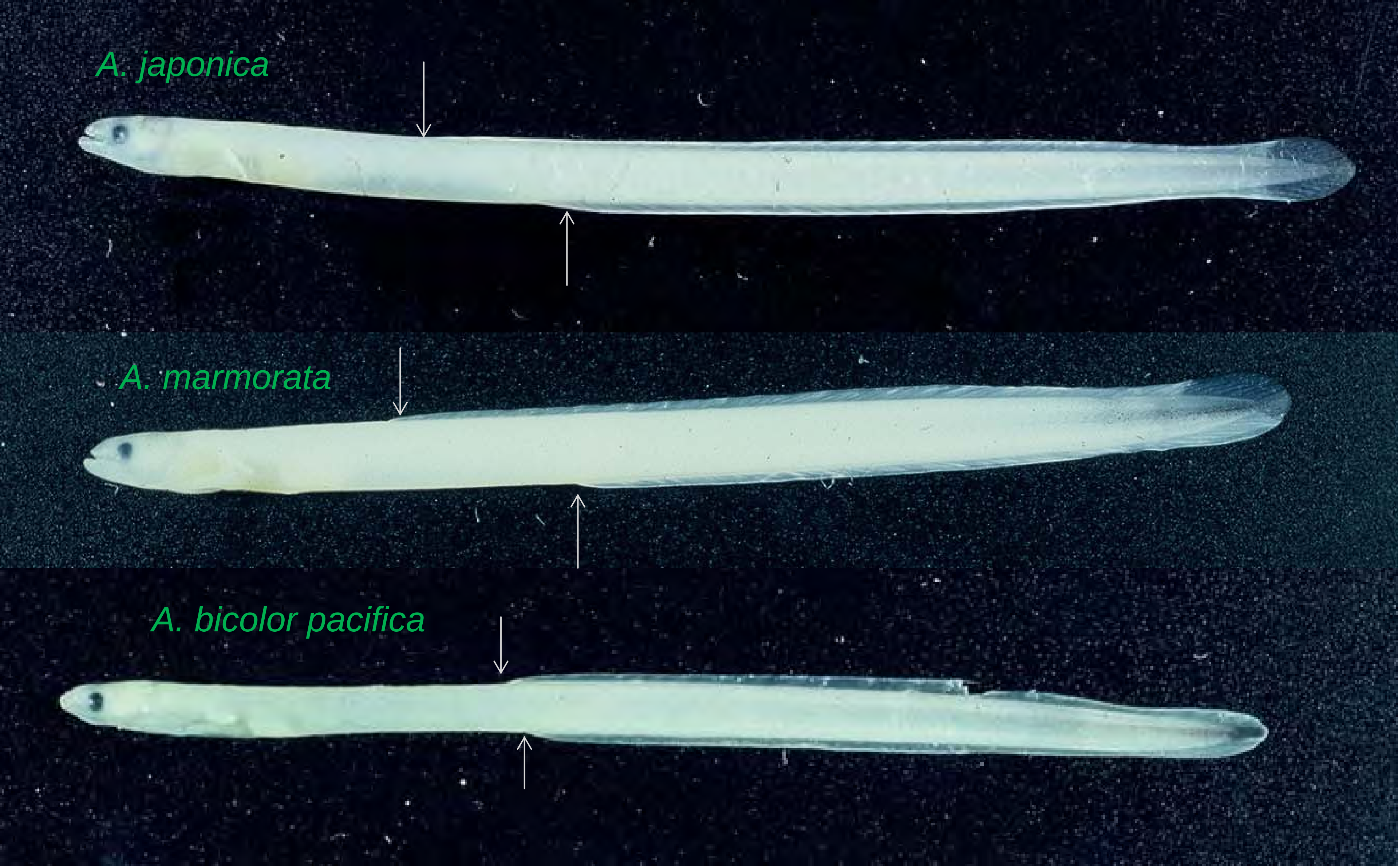
鰻魚(*Anguilla* spp) in Taiwan

	D. Fin	Dist.	Color
A. japonica 日本鰻	Long	Temperate	Uniform
A. marmorata 鱸鰻	Long	Tropical	Marble
A. celebesensis 西里伯斯鰻	Long	Tropical	Marble
A. bicolor pacific 太平洋雙色鰻	Short	Tropical	Uniform

New species(呂宋鰻*A. luzonensis*, or 黃氏鰻 *A. hungi*)

生活史至今仍然是謎。



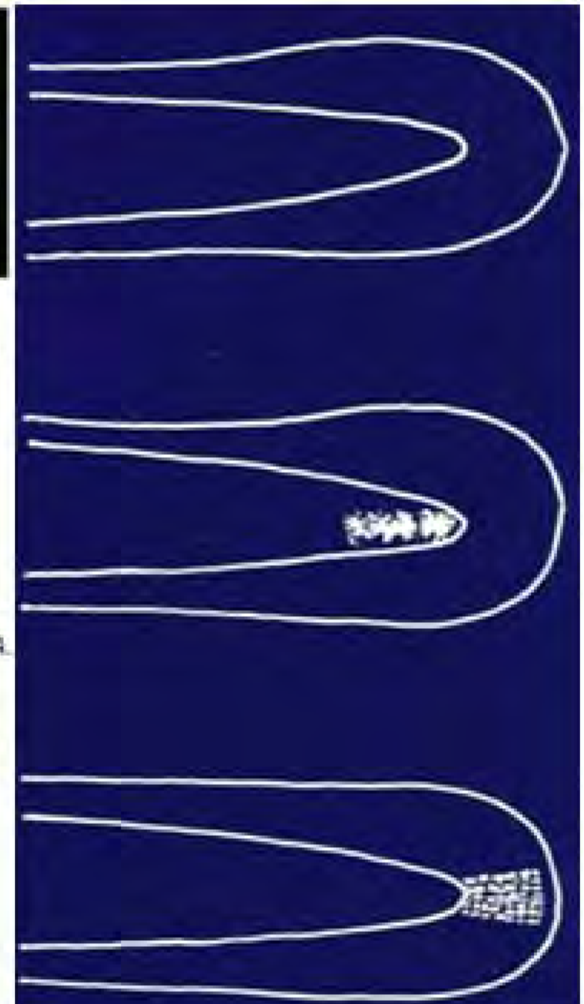
Longfinned eel: *A. japonica* and *A. marmorata*; shortfinned eel: *A. bicorlor pacifica*

The difference in pigmentation pattern of glass eel among species

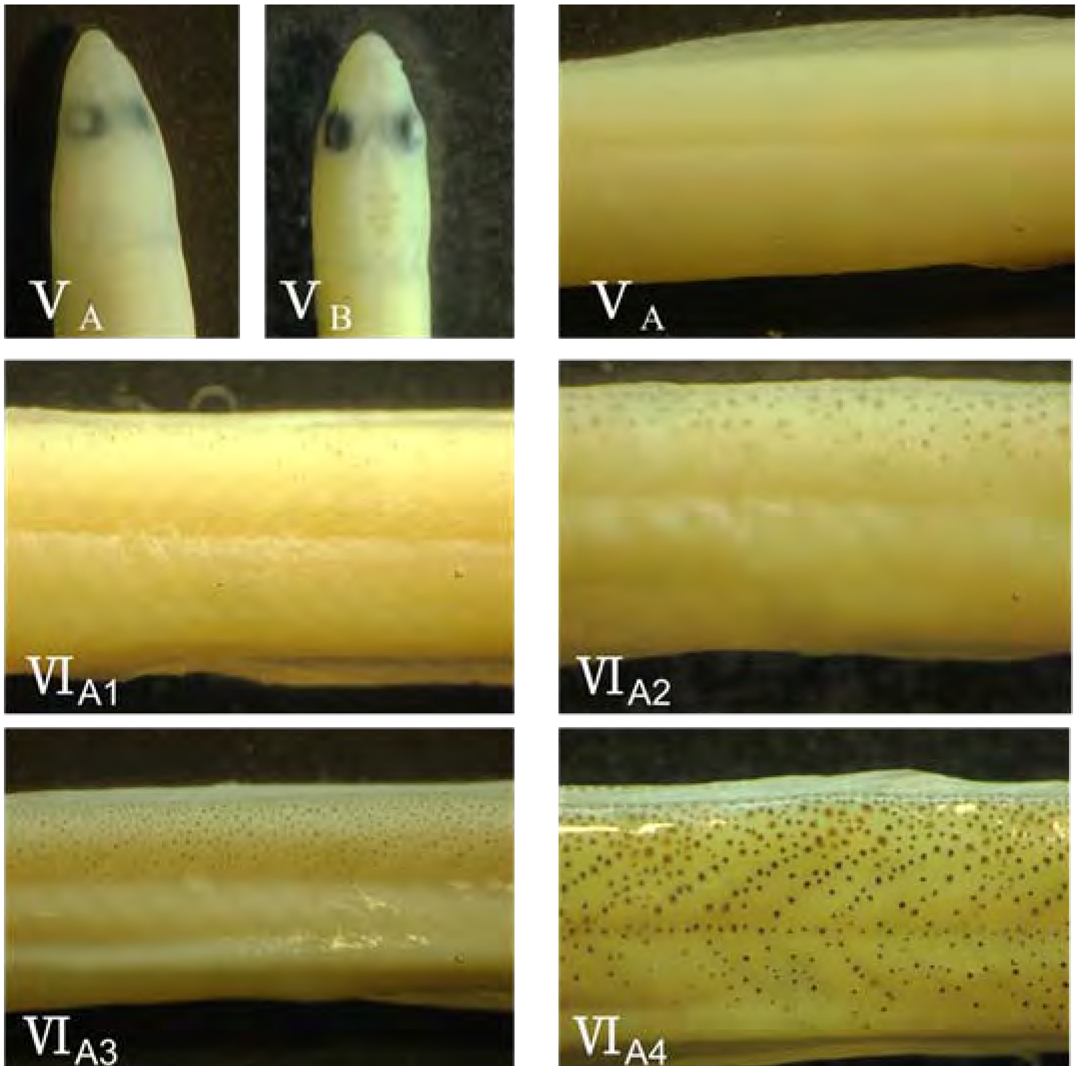
Anguilla japonica

Anguilla marmorata, A. luzonensis and A. celebesensis

Anguilla bicolor pacifica



Pigmentation stage of glass eel



Glass eel is called玻璃鳗 in Chinese and シラス(白子)ウナギ in Japanese.

Elver is called 鳗線in Chinese and クロコ(黑子) in Japanese。

The pigmentation stage is not very clear between glass eel and elver. In general, before VIA2 is glass eel, after VIA3 is elver(Fukuda 2010）

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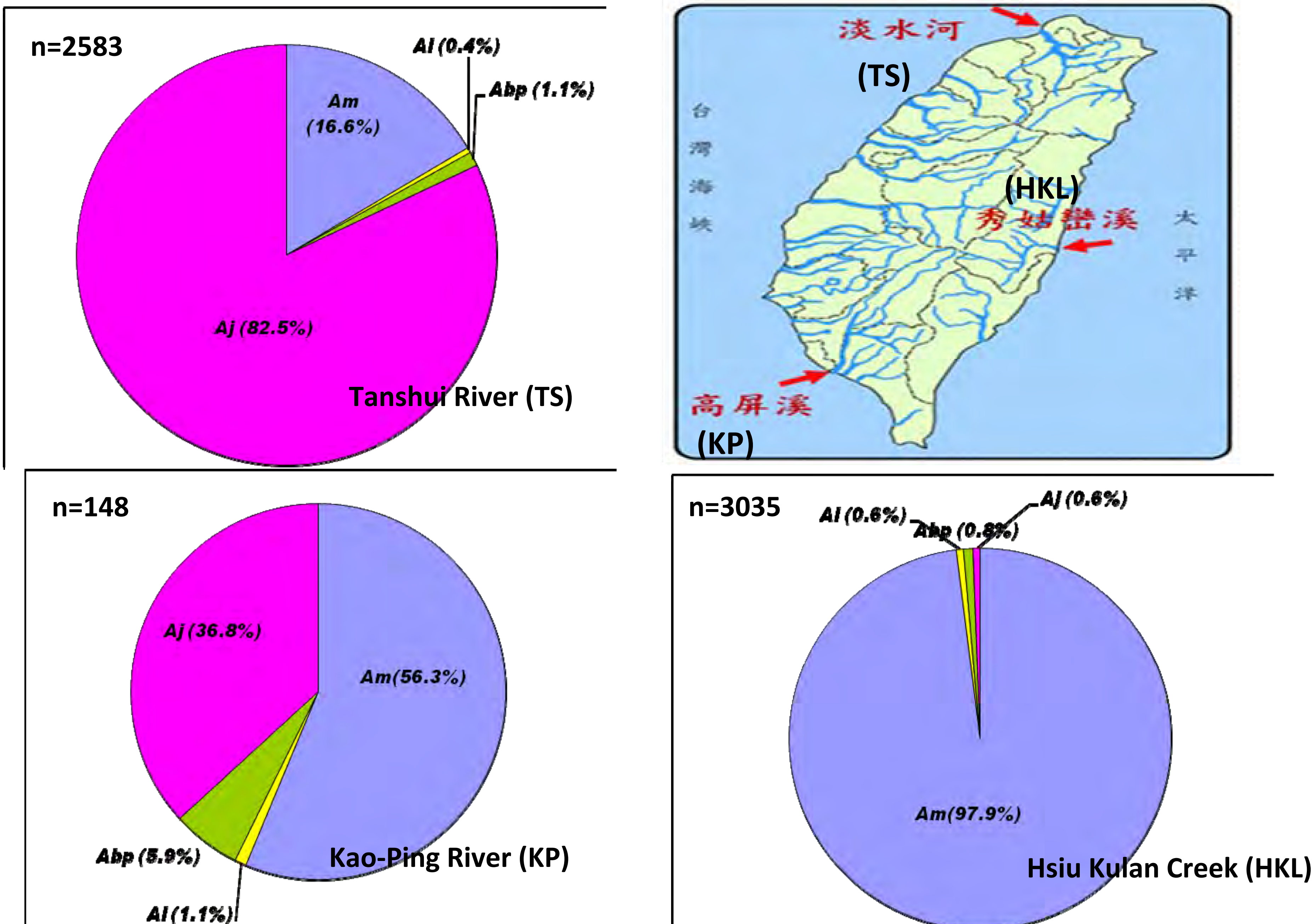
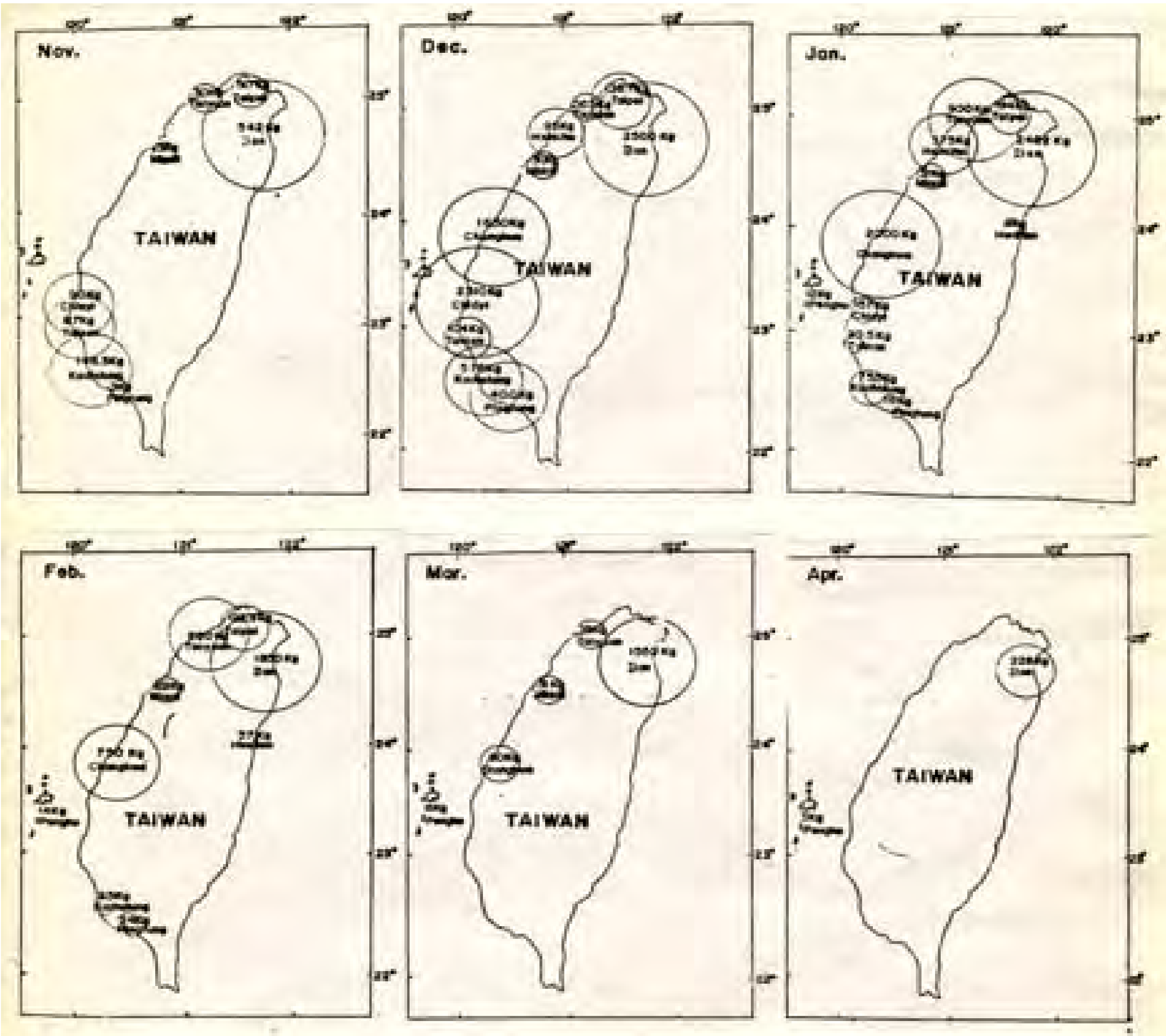


Species compositions of glass eels from Hsiukulan creek (HKL) of eastern Taiwan, and Tanshui River (TS) and Kao-Ping River (KP) of western Taiwan.

Seasonal and spatial distribution of the glass eel of Japanese eel in Taiwan



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2.3. The effects of environmental cues and the age of leptocephalus at metamorphosis on upstream migration timing of glass eel

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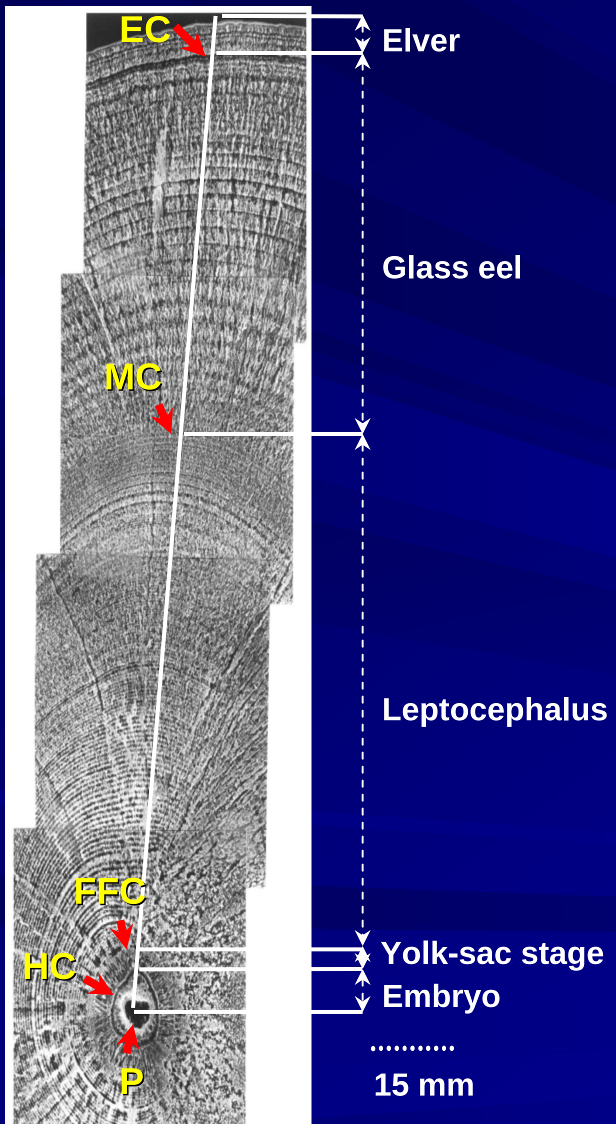
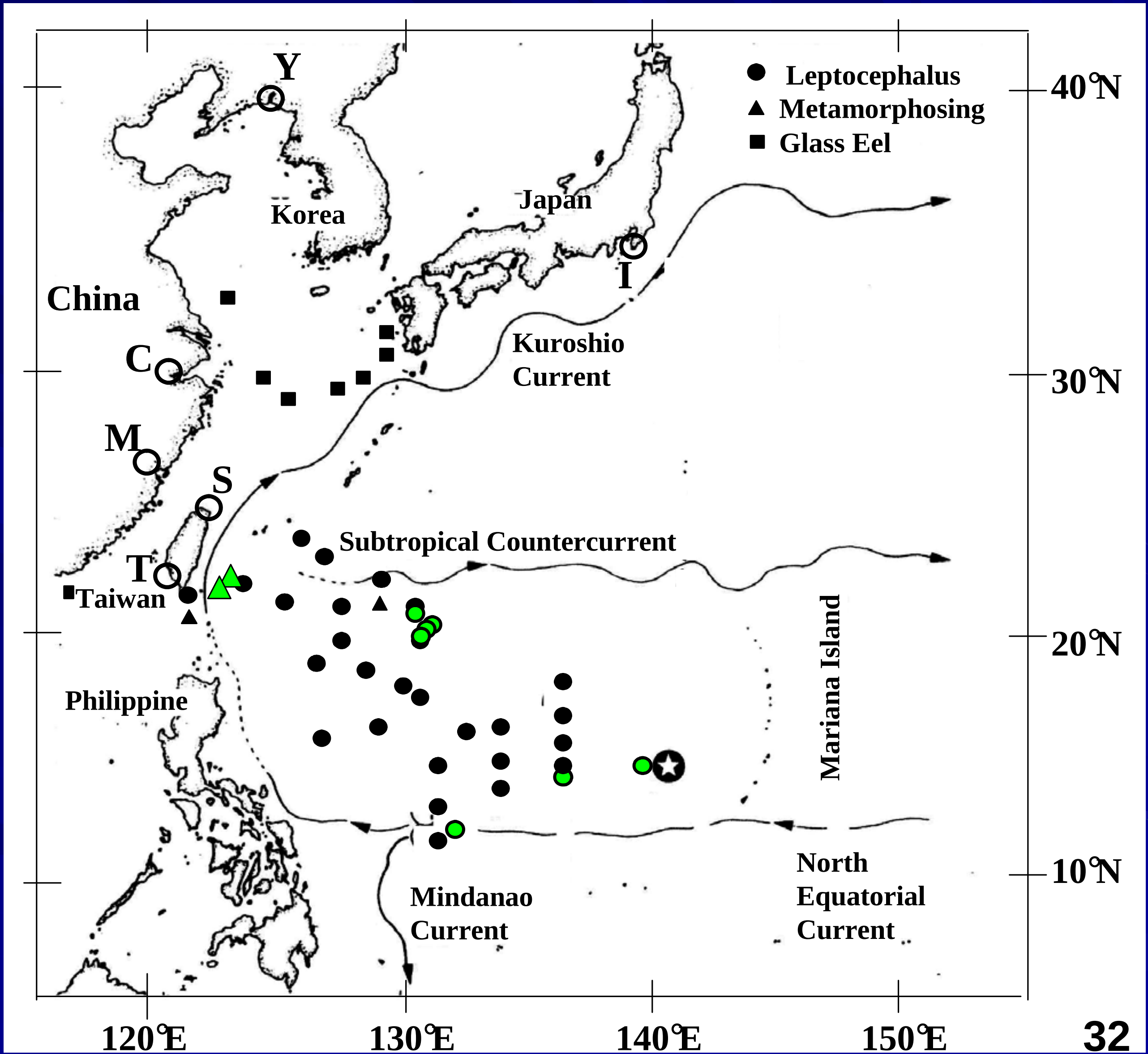
Ontogenetic change and dispersal process of the Japanese eel from spawning ground to the estuary

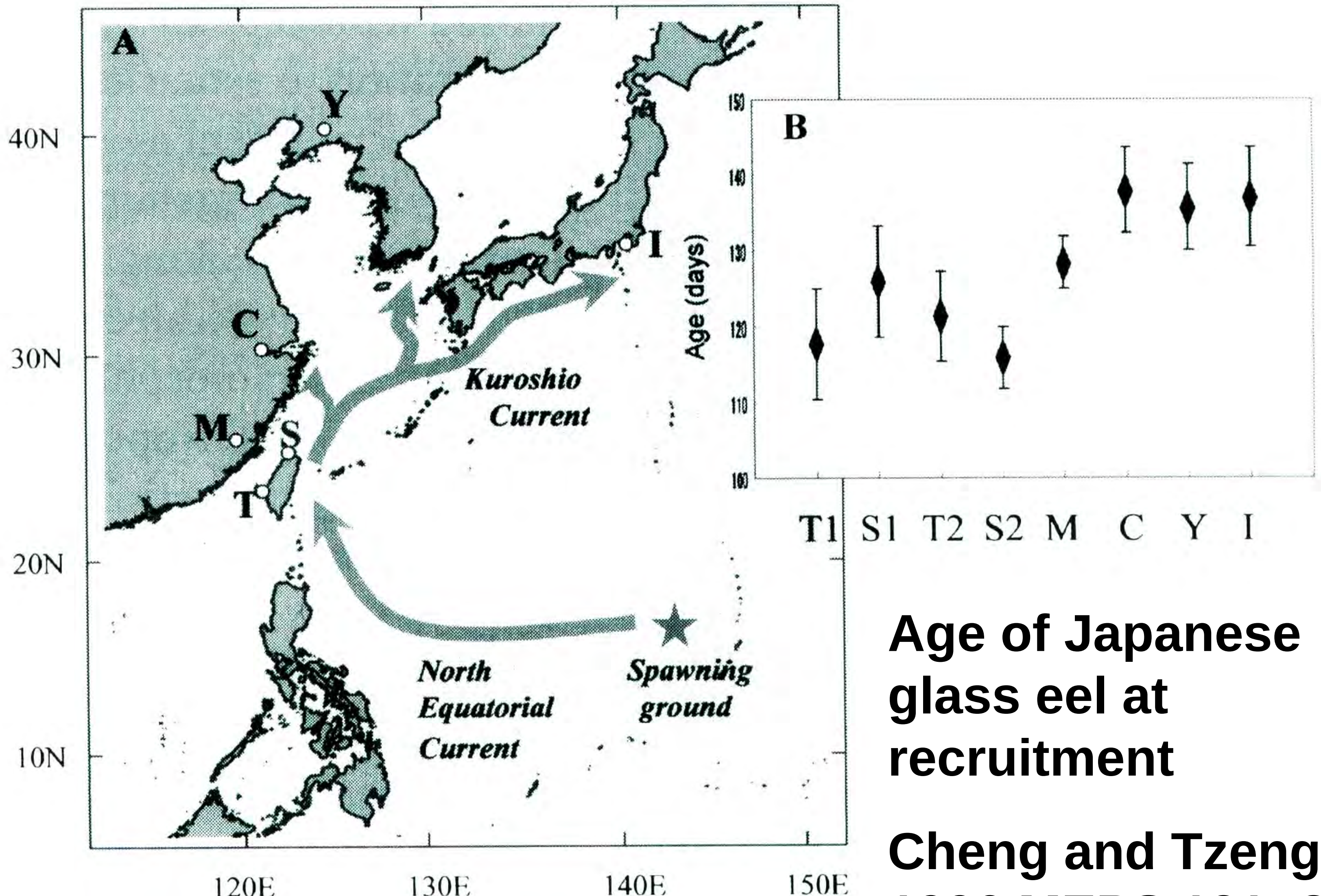




Leptocephalus metamorphosis timing and larval dispersal distance

Sampling site		Date	Size	Total length	T_m	$T_{r\text{-}m}$
Taiwan	T_1(South)	30-Dec-92	30 (16)	57.0±2.0	117.7±14.3	39.2±6.8
	T_2	24-Mar-93	30 (14)	56.1±2.4	121.4±12.0	42.9±6.2
	S_1(North)	30-Dec-92	30 (12)	56.8±2.3	125.9±14.7	31.7±7.6
	S_2	17-Feb-93	30 (13)	55.9±2.2	115.8±8.1	38.9±5.8
China	M	1-Mar-93	30 (20)	55.1±1.9	128.4±6.9	34.5±3.6
	C	17-Feb-93	30 (23)	55.6±1.9	137.9±11.3	38.6±5.7
	Y	3-May-93	30 (23)	58.3±1.8	135.5±11.3	42.8±7.4
Japan	I	10-Jan-94	30 (10)	57.4±2.3	137.0±12.9	45.0±9.2

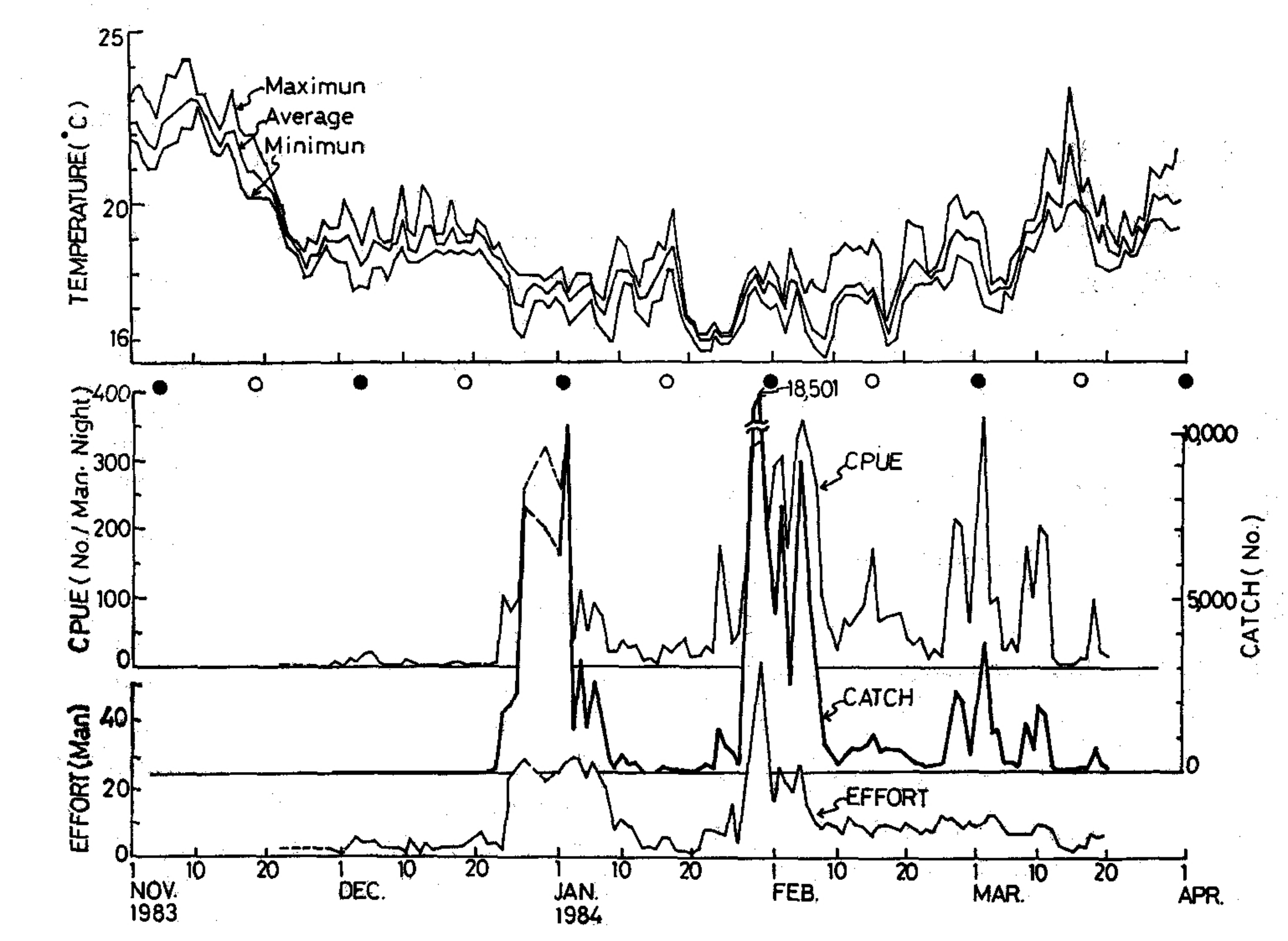
$$d = \nu \times \triangle t$$
$$= 96 \text{ km d}^{-1} \times 21\text{d}$$
$$= 2016 \text{ km}$$



Age of Japanese glass eel at recruitment

Cheng and Tzeng 1996 MEPS 131: 87-96

鰻線漁獲量的日變化與月齡、水溫之關係



Tzeng (1985) Jap Soc Fish Oceanogr 47/48: 11-28

Biological rhythm and zetegiber

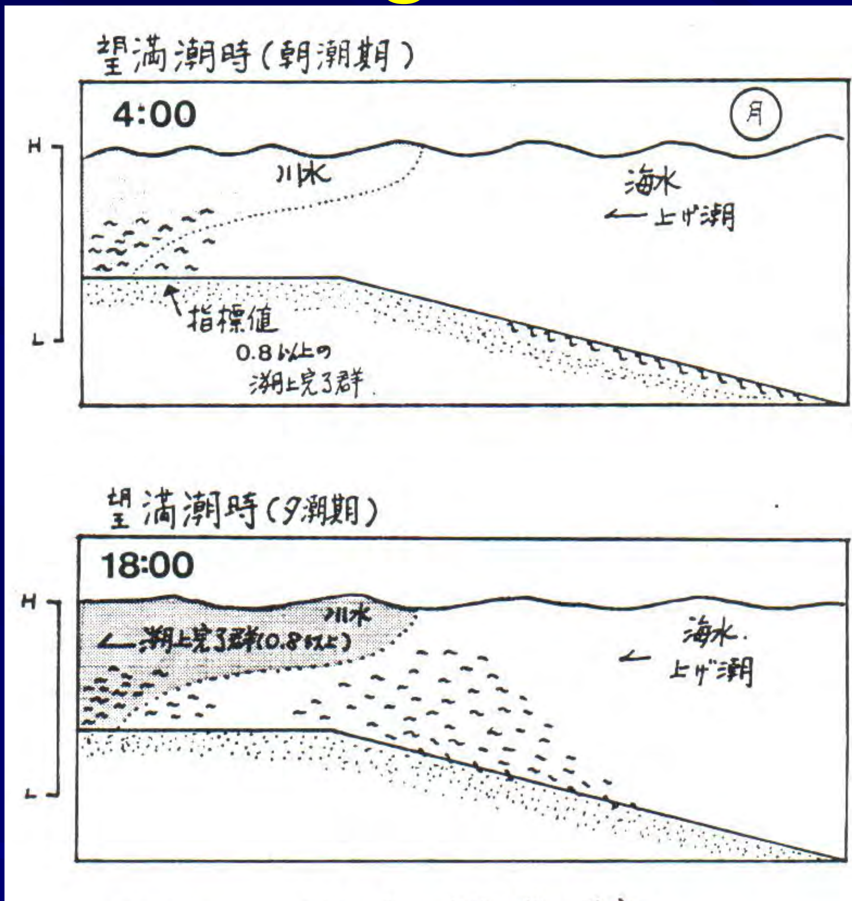


図 5 1　シラスウナギ魚群の行動

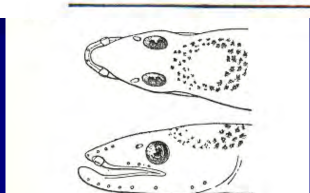
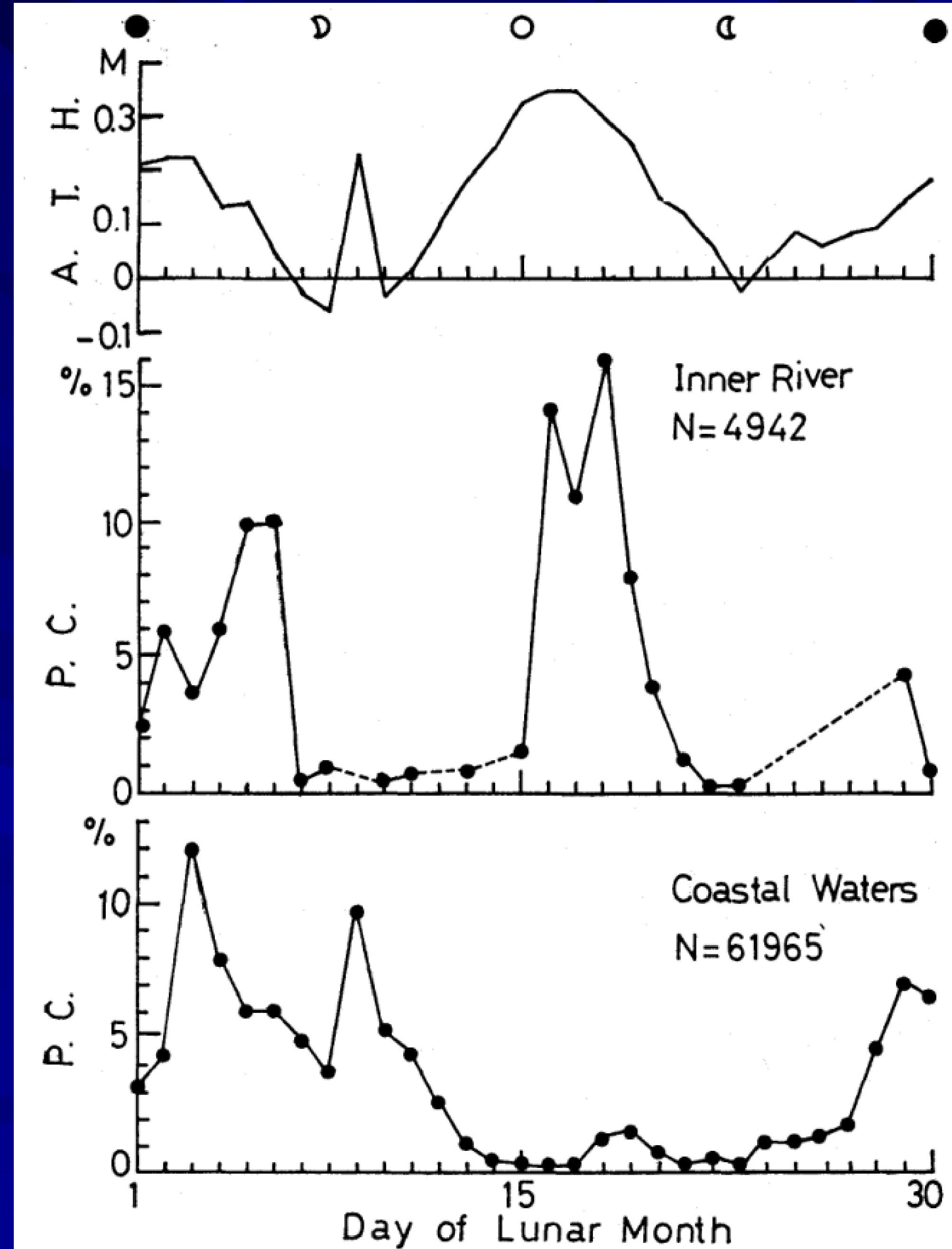


FIG. 44. Cerebral pigmentation in the elver at stage VB (after G. Gilson).



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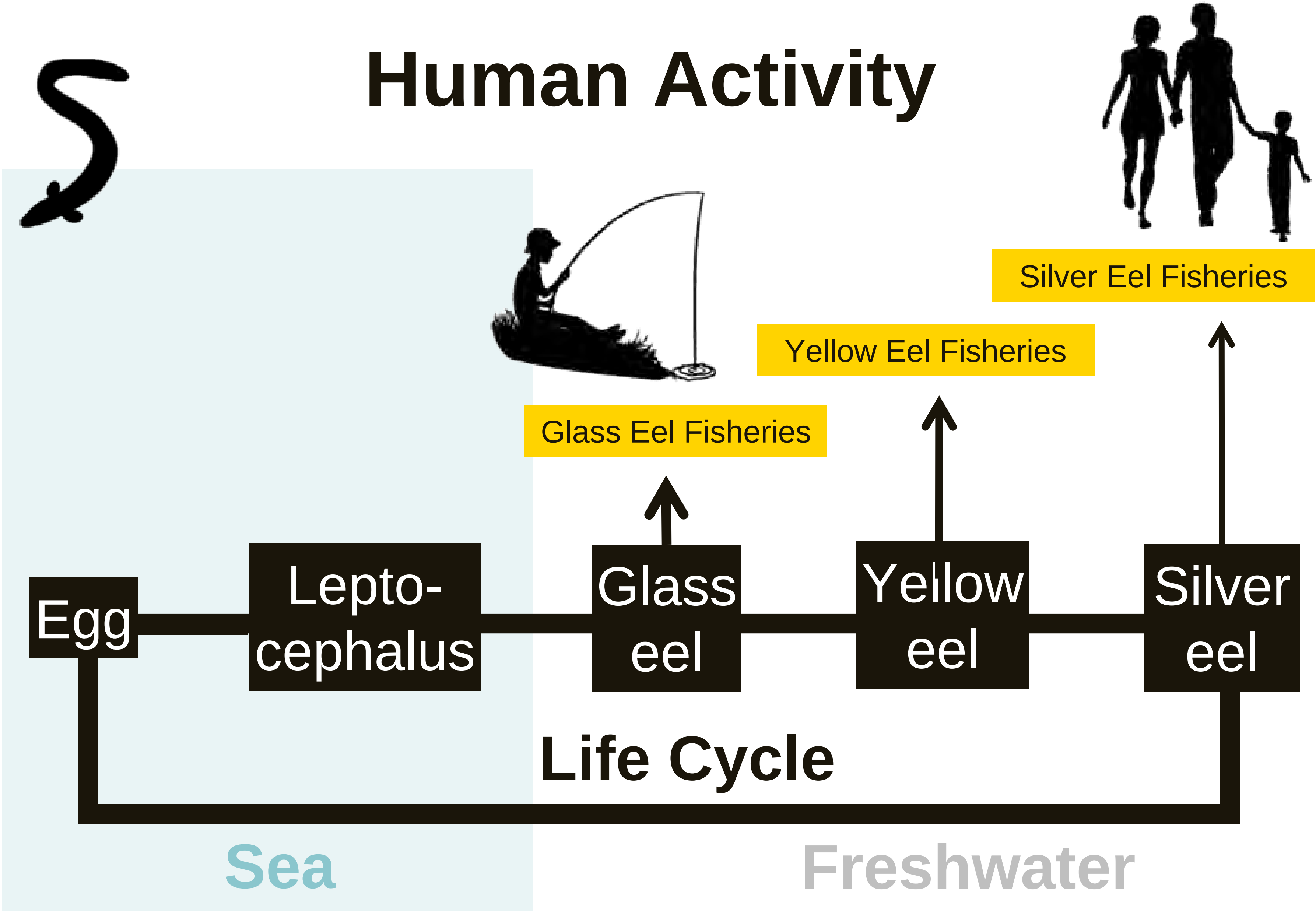


All stages of eels in freshwater are heavily exploited

The exploitation rate of glass eel in Taiwan, 54 to 75 %, estimated from each of the recruitment wave in the fishing season 1982-83(Tzeng 1984)

TABLE 1

The initial population size (N_0), catchability (q) and rate of exploitation (E) estimated from the regression of CPUE on cumulative fishing effort based on catch data of 7 immigrating shoals of elvers

Duration: Fishing Date	Duration: days	ΣX_t	ΣC_t	r	F-value	Estimated parameter: N_0	Estimated parameter: q	Rate of exploitation
1. Dec. 17–25, 1982	9	209	15817	−0.977	148.955**	23,780.9	0.01077	66.5%
2. Jan. 2–5, 1983	4	25	1022	−0.885	7.196^{ns}	1,461.9	0.04906	69.9
3. Jan. 11–16	6	88	3516	−0.925	23.635**	7,973.4	0.00705	44.1
4. Jan. 23–28	6	97	6607	−0.915	20.519*	12,252.8	0.03517	53.9
5. Feb. 13–18	6	150	9118	−0.945	33.260**	16,492.1	0.00636	55.3
6. Feb. 21–26	6	58	1890	−0.984	125.213**	2,518.3	0.04378	75.1
7. Mar. 13–17	5	24	691	−0.966	36.325**	916.4	0.06055	75.4

ΣX_t: cumulative fishing effort in man-night

ΣC_t: cumulative catch in number of elvers

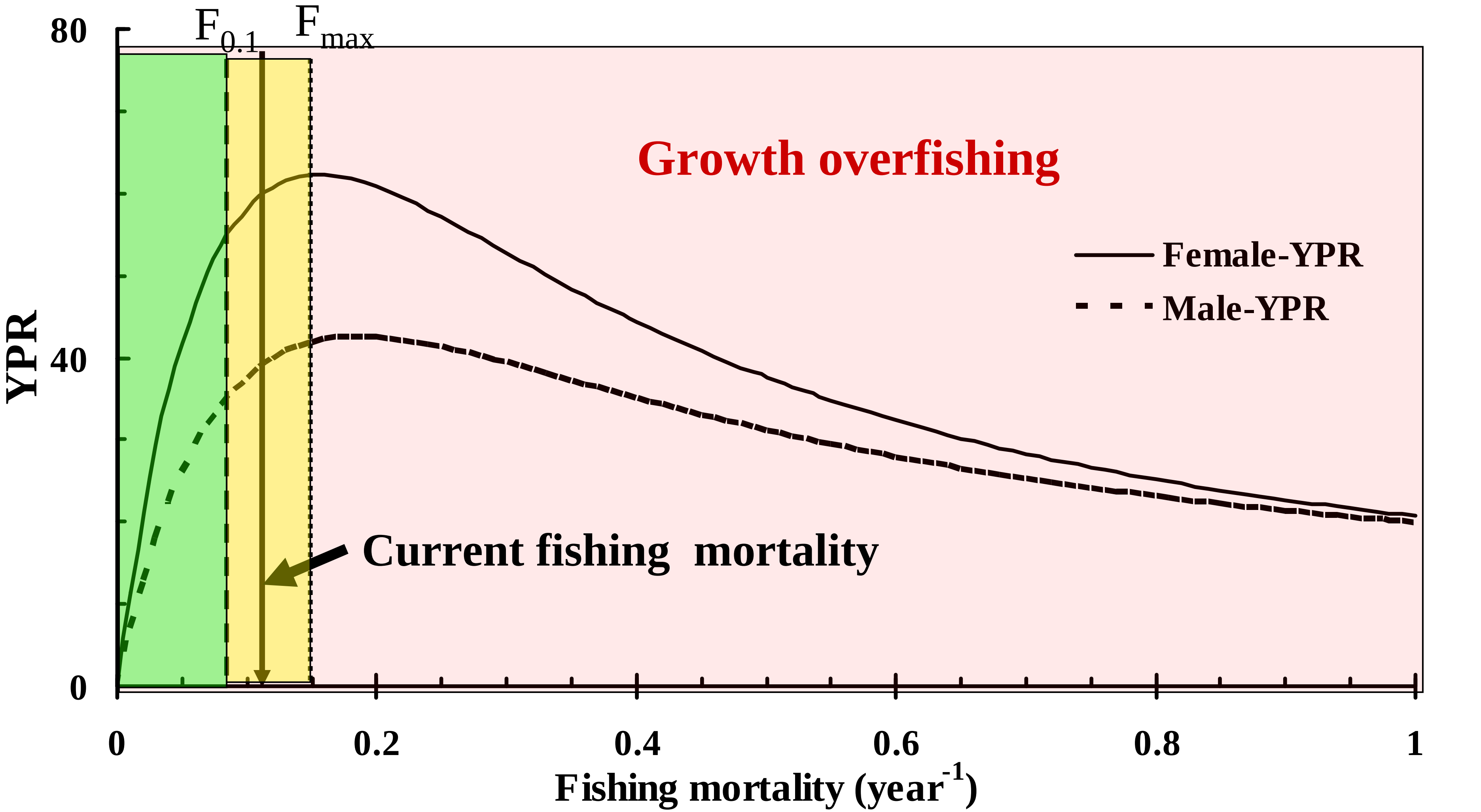
r: correlation coefficient

F-value: the probability of significance of regression line is given as *: 5%, **: 1%, ns: non-significance.

Depletion method: CPUE= *q No* - Sum *Xt*

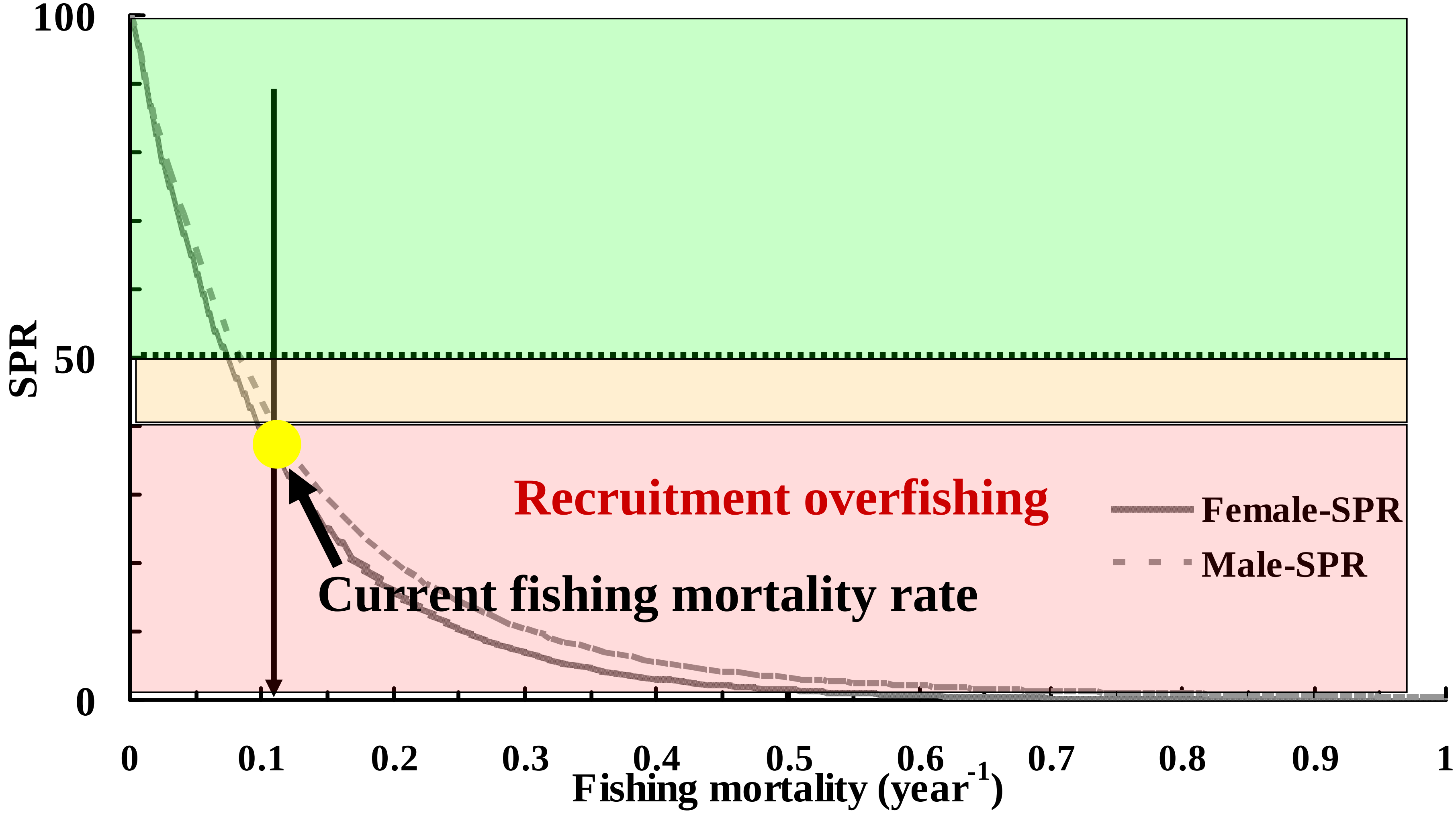
Yield-Per-Recruit model analysis

Growth overfishing is closed



Spawner-per-recruit model:

Recruitment overfishing might have occurred



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成育場
東アジア
韓国
日本
中国
黒潮
台湾
北赤道海流
マリアナ海溝
ミンダナオ海流
繁殖場
西マリアナ海嶺南端

Table 1. Results of regression analyses of $\log_{10}$(eel catch) against climate indices.

	Annual	Spring	Summer	Autumn	Winter
Precipitation	NS	NS	NS	NS	−0.316(1 yr)
NEC	−0.310(3 yr)	NS	−0.343(3 yr)	−0.282(1 yr)	NS
Niño3.4	NS	NS	NS	NS	NS
Niño4	NS	NS	NS	NS	NS
Niño3	NS	NS	NS	NS	NS
Niño1.2	NS	NS	NS	NS	NS
SOI	NS	NS	NS	NS	NS
QBO	−0.272(3 yr)	−0.339(1 yr) 0.394(2 yr)	−0.287(3 yr)	0.286(1 yr)	−0.320(0 yr)
NPGO	NS	NS	NS	NS	−0.334(1 yr)
PDO	−0.308(1 yr)	−0.399(2 yr)	NS	NS	−0.449(1 yr)
NPI	NS	NS	NS	NS	0.291(1 yr)
WPO	0.289(2 yr)	NS	0.472(1 yr)	0.417(1 yr)	NS
Eddy kinetic energy	NS	NS	NS	NS	NS
Sunspot	0.328(0 yr)	0.306(0 yr)	0.309(0 yr)	NS	0.367(0 yr)

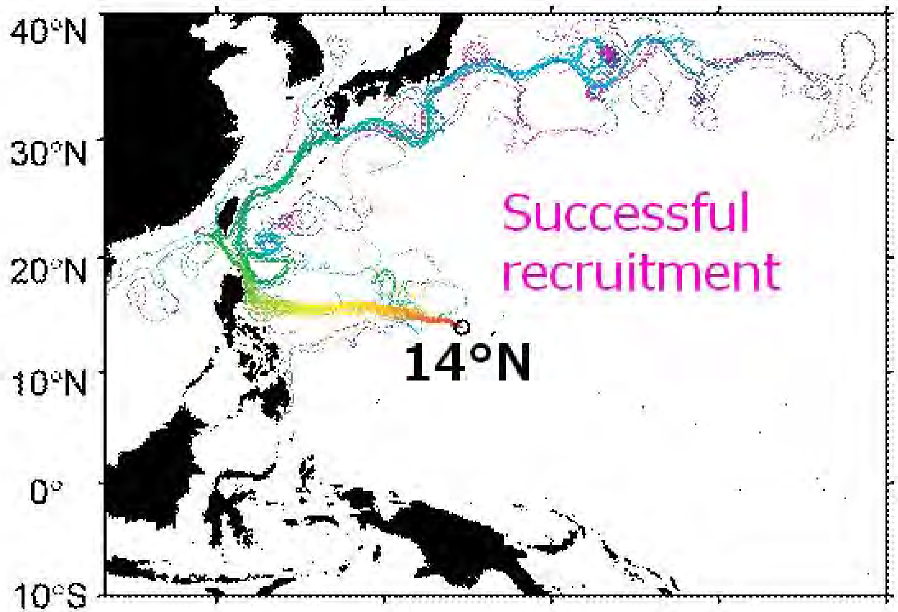
Autocorrelation is accounted for using estimated generalized least squares. Data are normalized to unit mean and variance before analyses. When correlations are significant for multiple lags, all significant correlations are presented. The full table is provided in Supporting Information S1.

Only the regression coefficient significant at $p<0.05$ is presented. NS indicates that no significant correlation was found in all lags (0 to 5 years). Parenthesis encloses the years that the climate index leads the eel catches. We investigated the lag up to 5 years. For QBO, correlation beyond 3 years is omitted, considering its biennial nature.

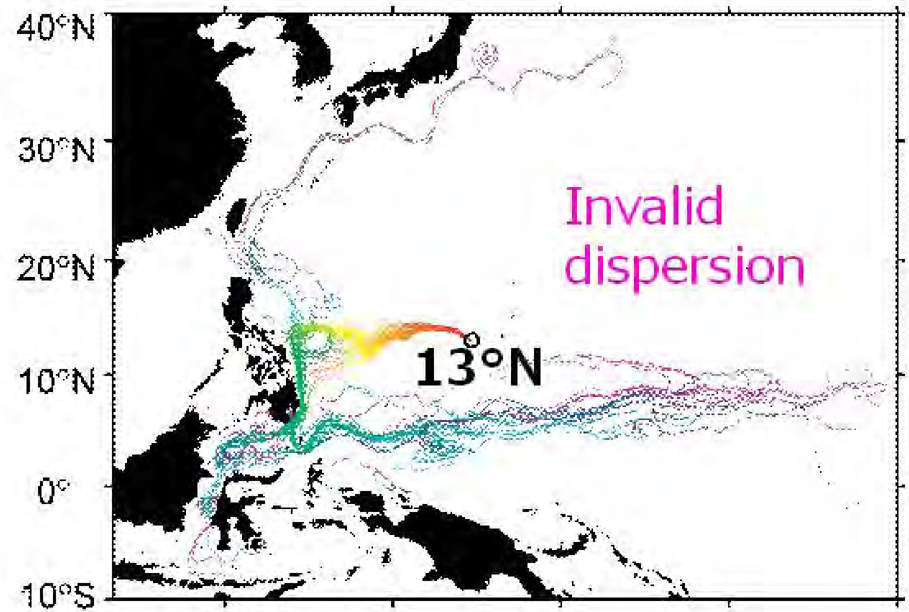
doi:10.1371/journal.pone.0030805.t001

Tzeng W-N, Tseng Y-H, Han Y-S, Hsu C-C, et al. (2012) Evaluation of Multi-Scale Climate Effects on Annual Recruitment Levels of the Japanese Eel, *Anguilla japonica*, to Taiwan. PLoS ONE 7(2): e30805. doi:10.1371/journal.pone.0030805

http://www.plosone.org/article/info:doi/10.1371/journal.pone.0030805

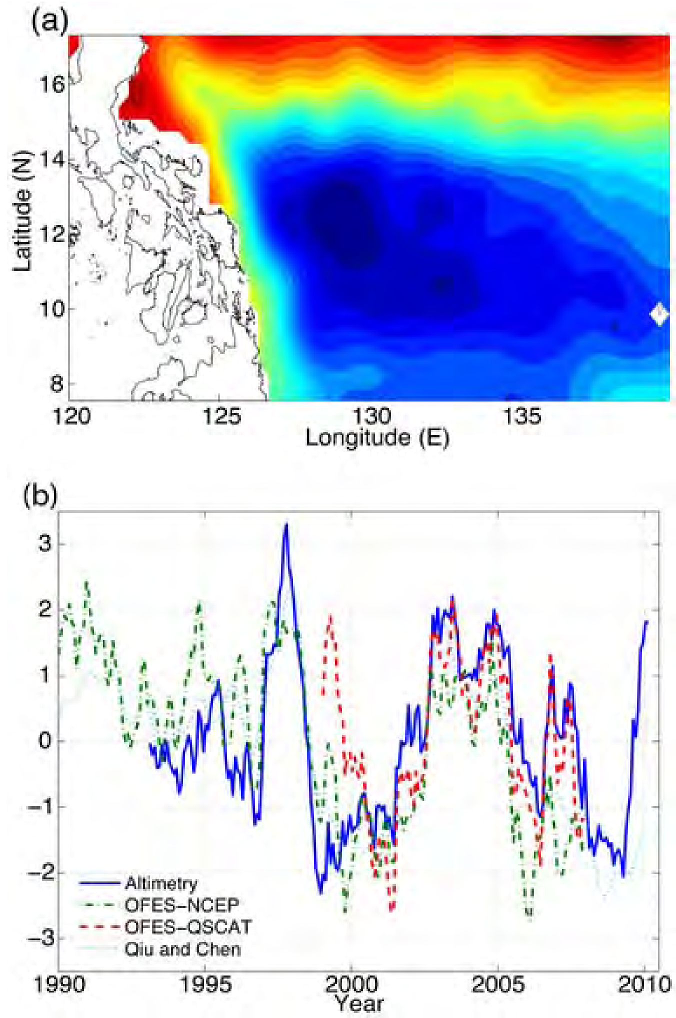


Entrainment into Kuroshio Current



Entrainment into Mindanao Current

Figure 2. Index for latitudinal shift of NEC bifurcation.



Tzeng W-N, Tseng Y-H, Han Y-S, Hsu C-C, et al. (2012) Evaluation of Multi-Scale Climate Effects on Annual Recruitment Levels of the Japanese Eel, *Anguilla japonica*, to Taiwan. PLoS ONE 7(2): e30805. doi:10.1371/journal.pone.0030805
http://www.plosone.org/article/info:doi/10.1371/journal.pone.0030805

2) A weak coherence between Eel vs Summer NEC occurs at the time scale of 5 to 7 year, which have not been found in long-term correlation analysis in Table 1.

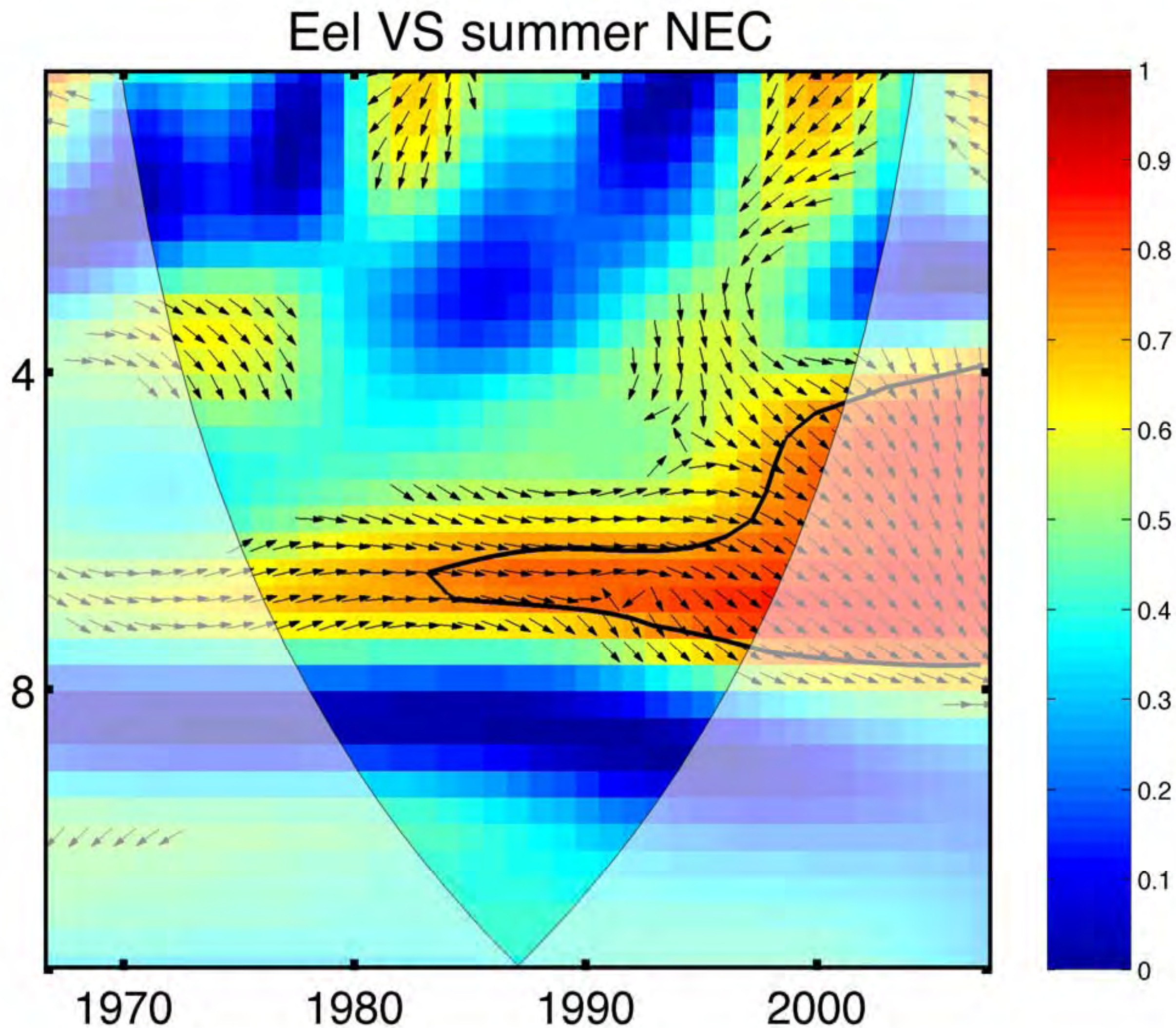


Fig. 4b

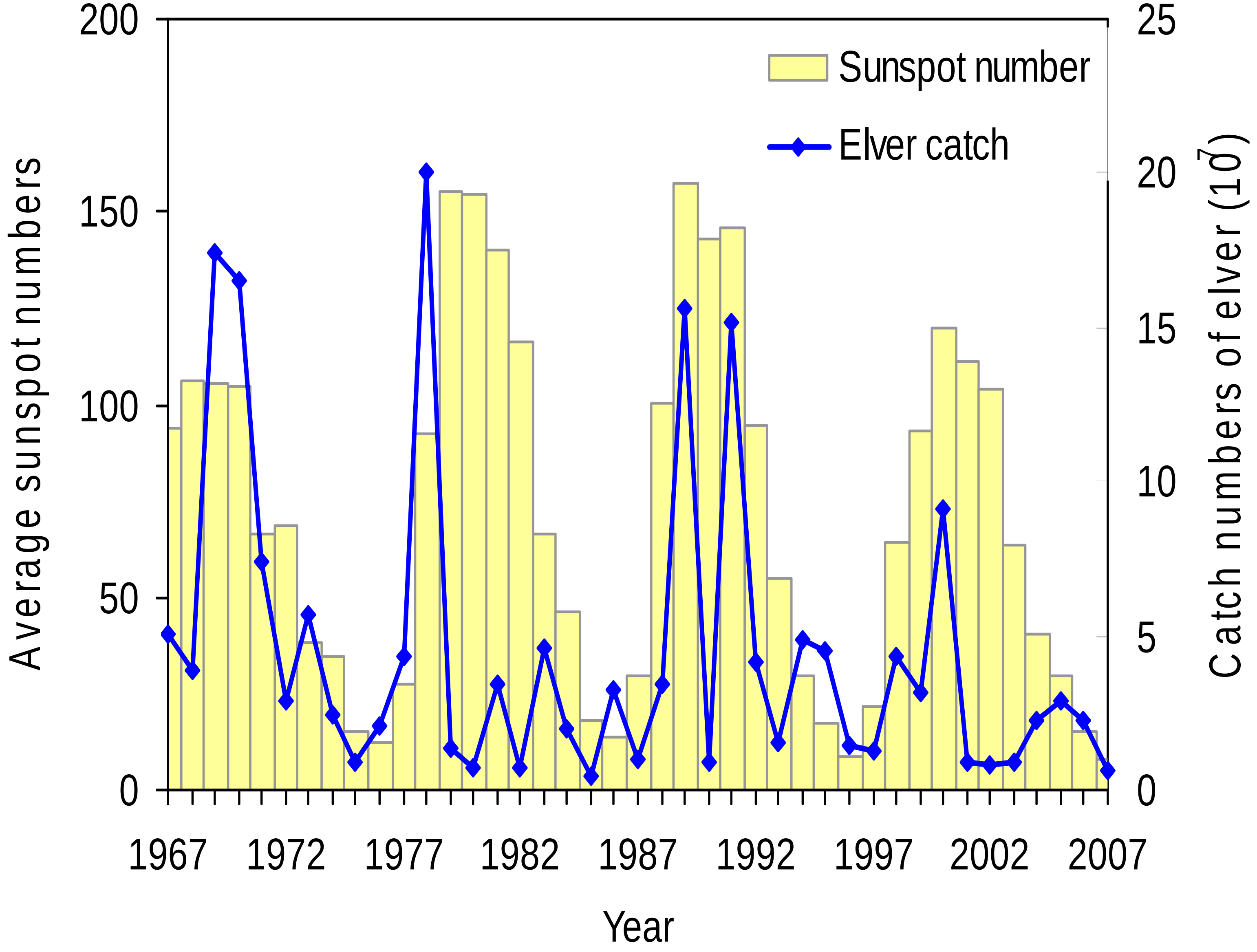


Fig. 2 Time series change of sunspot and glass eel (elver) catch in Taiwan, 1967-2008.

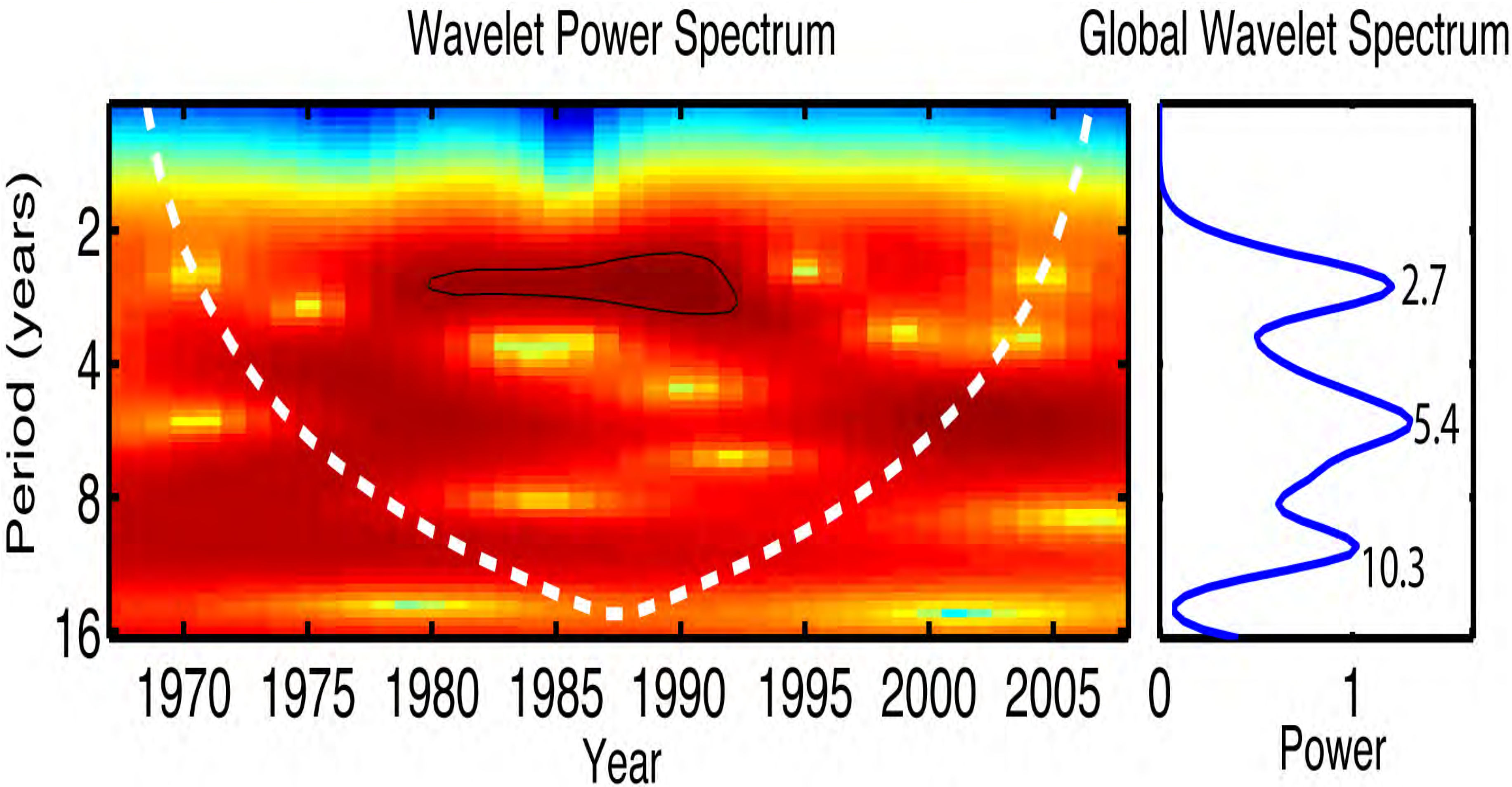


Fig. 3 Wavelet power spectrum (left) and global power spectrum (right) of log10(eel catch).

The cross wavelet coherence analyses between various climate change indexes and glass eel catch are as follows:

1) A strong positive coherence between Eel vs sunspot occurs at the scale of 10 to 13 years (Fig. 4a)

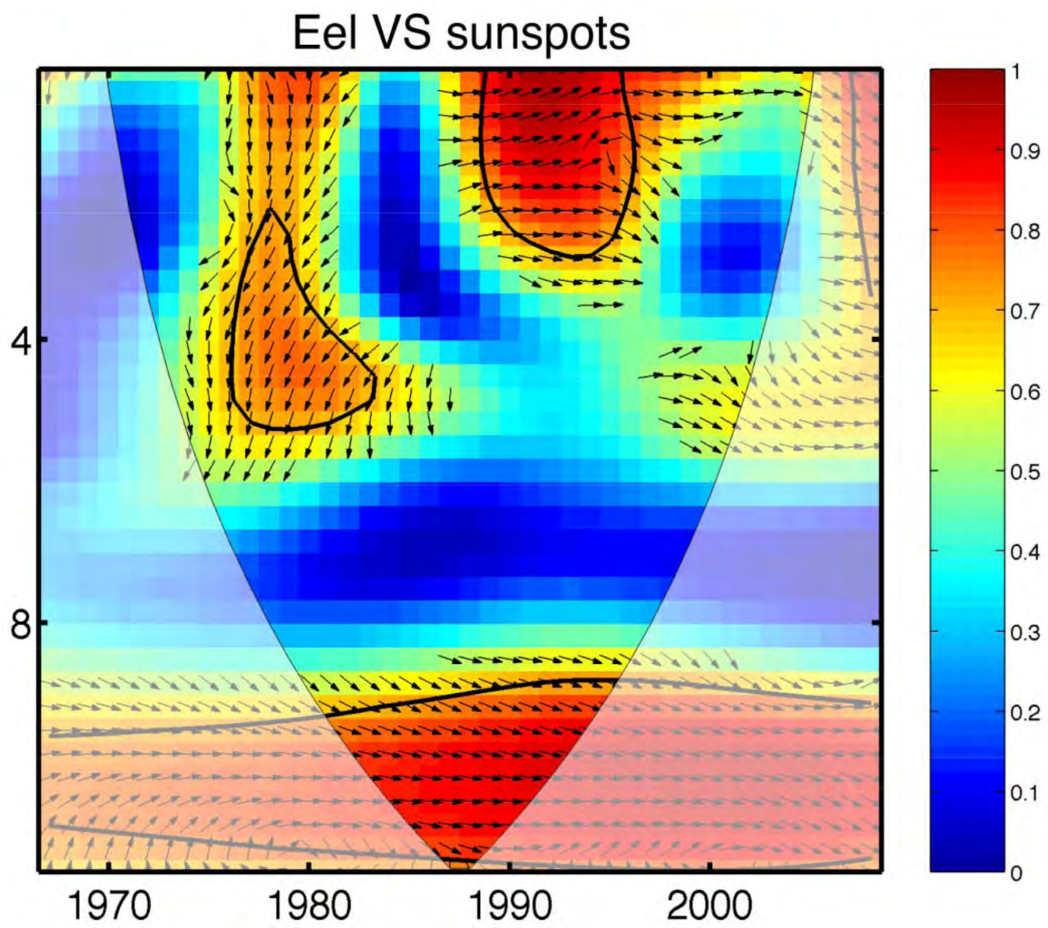
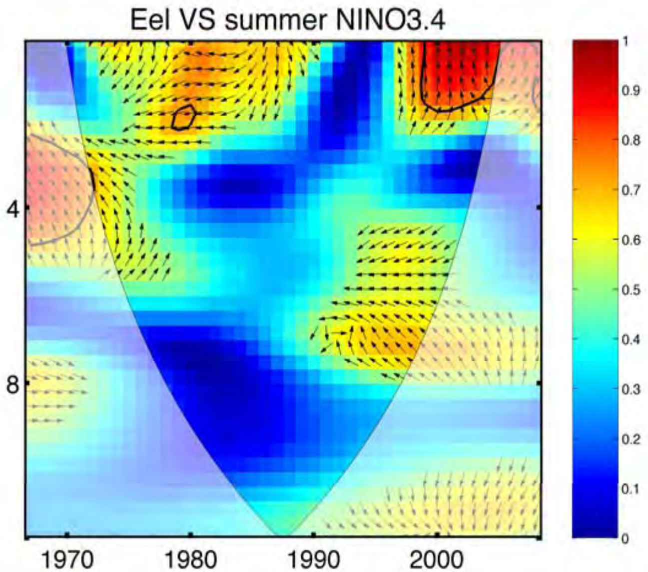
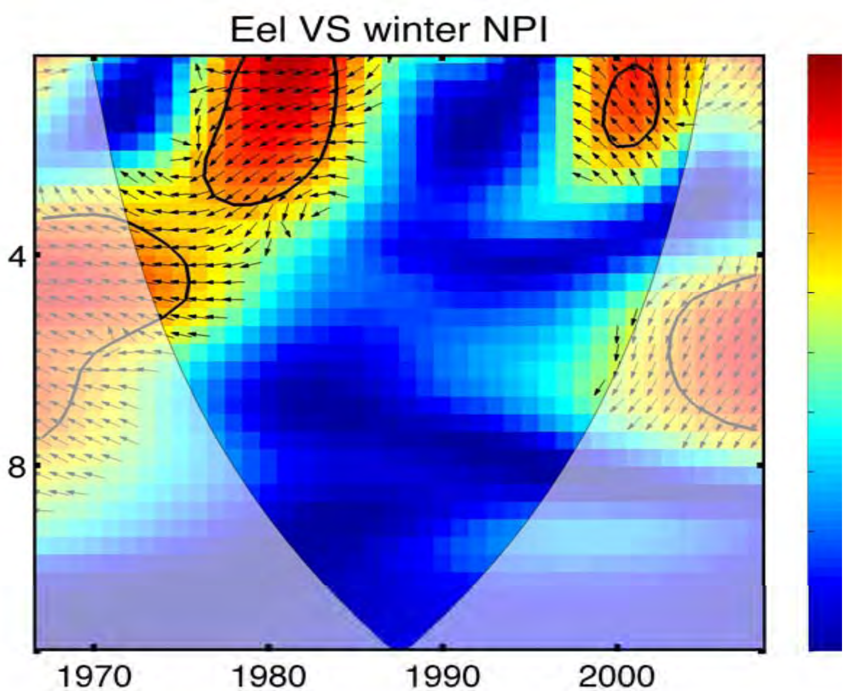
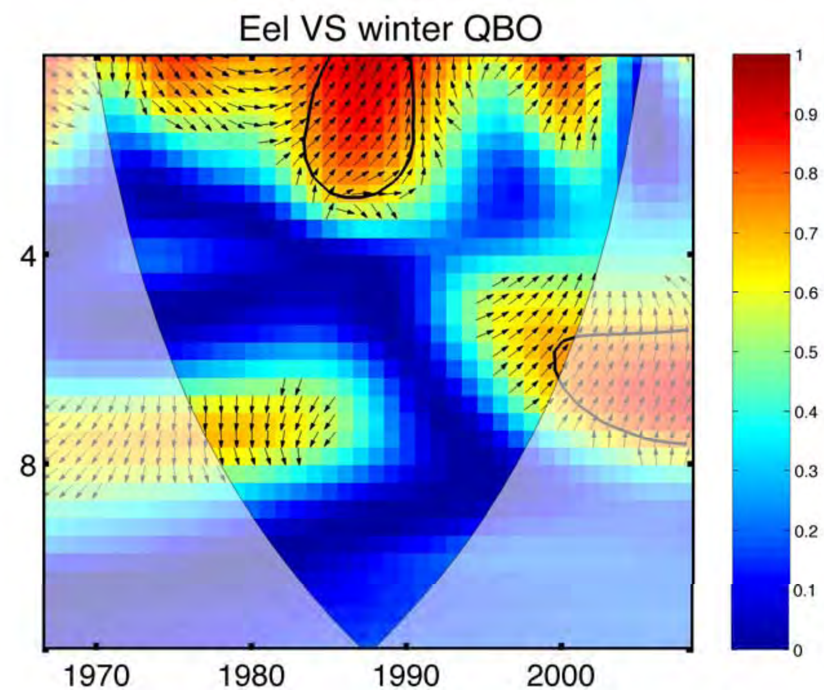


Fig. 4a



3) The eel catch in relation to the climate indexes such as NINO3.4 (El Nino near equatorial) , NPI(North Pacific Index, a sea level pressure in the region of 30o-65oN, 160oE-145oW, derived from SST), and QBO(Quasi Biannual Oscillation, an east-westward wind field) changed with a 1-3 year high frequency correlation (Figs. 4c-e).





4) On the contrary, the eel catch in relation to WPO (Western Pacific Oscillation, a low altitude (500mb) high pressure center in the eastern Japan) changed with a 9-13 year low frequency correlation(Fig.4f).

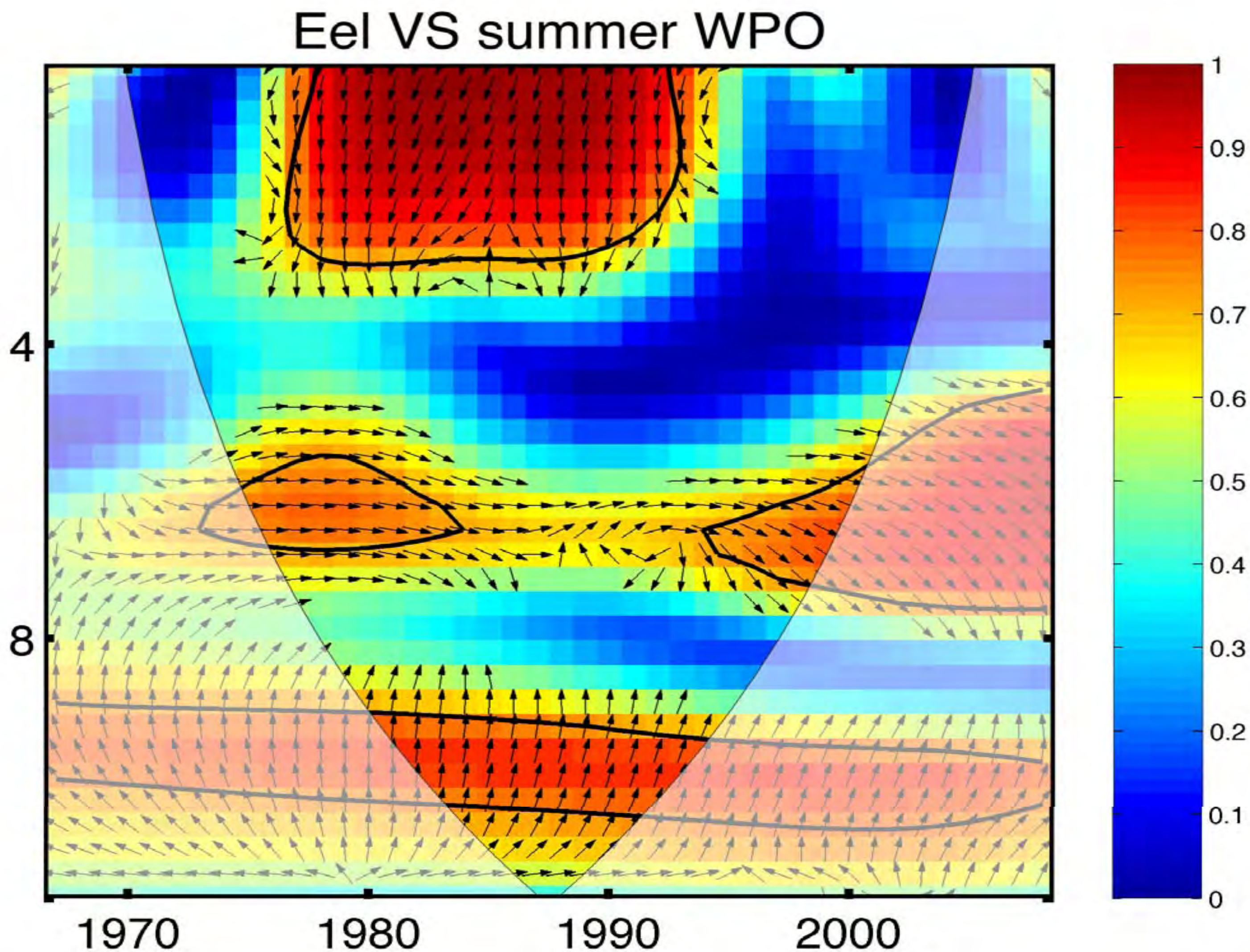


Fig.4f

5) Meanwhile, the coherence between summer WPO vs annual sunspots indicated sunspots may lead the change of WPO at the time scale of 9-13 years (Fig.4g).

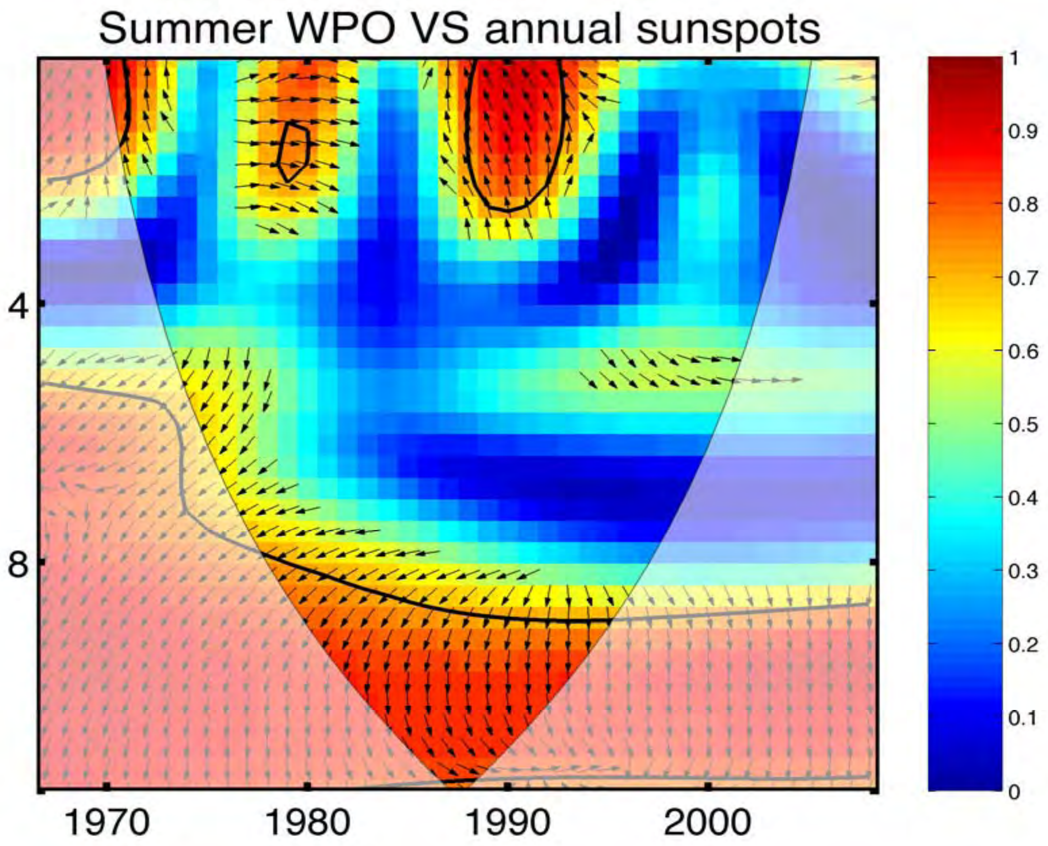


Fig.4f

The wavelet coherence between various climate change indexes and log10(eel catch) indicated that the catch of glass eel was affected by various climate indexes at different time scale

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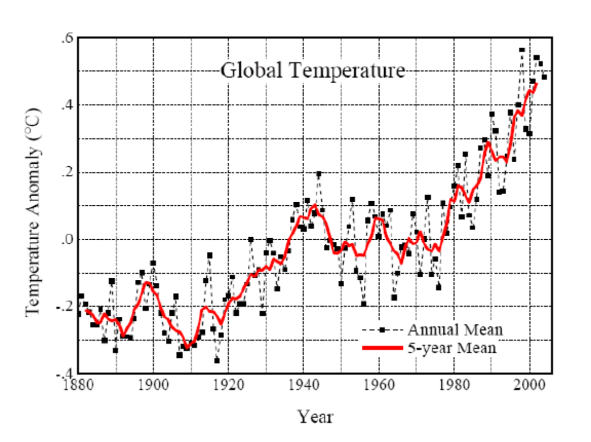
Why eel resource decline ?

Habitat degradation

Glass eel overfishing

Global climate change

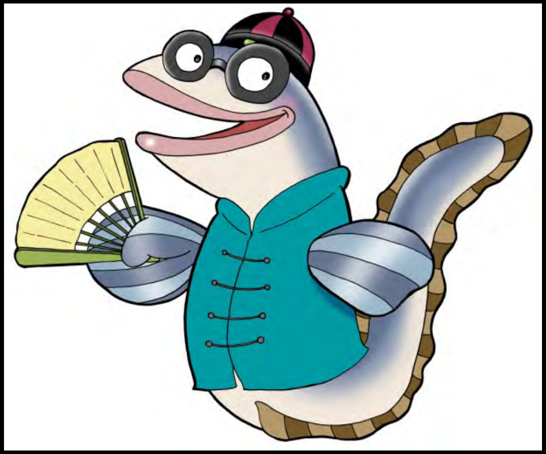


Discussion and conclusion

Strategy for sustaining the eel aquaculture industry and fisheries

- To solve the glass eel crisis for the in-sufficient *A. japonica* glass eel for aquaculture, the development of the aquaculture techniques of exotic eel species (such as *A. marmorata*, *A. bicolor*, *A. mossanbica*) is necessary
- To reduce the catch of the glass eel of *A. japonica* because of over exploitation.
- To stop the yellow eel fishery in the river and to increase the escapement of the silver eel for the recovery of glass eel of *A. japonica*
- The long-term glass eel catch decline in Taiwan depends on population level itself, similar to the other countries.
- In addition, Taiwan is located in the edge of the distribution of Japanese eel in the western Pacific, that lead to the climate change effect on the catch of glass eel is more sensitive in Taiwan than other counties. The catch of glass eel was highly correlated with various climate transportation might be influenced by the climate changes that are originally governed by the solar activity.

Thank You for Your Attention



Acknowledgement:

National Science Council, Republic of China
Fishery Agency, Council of Agriculture, ROC
Dr. Kazuo Uchida the Head of Freshwater Fisheries Research Division, National Research Institute of Aquaculture, FRA

Acknowledgements

Thanks to Dr. Kazuo Uchida, and Dr. Tatsu Kishida for inviting me to present this paper in the 2012 PICES eel workshop, Hiroshima.
Thanks also extend to the National Science Council and Fishery Agency, Council of Agriculture of Taiwan for their financial support on our long-term eel researches as well as the student of our team.

Eel field study in NW Luzon Philippine on Jan 18, 2009 before Chinese Lunar New Year