Ecosystem responses to anthropogenic activities and natural stressors among inland, shelf and oceanic waters in the western North Pacific

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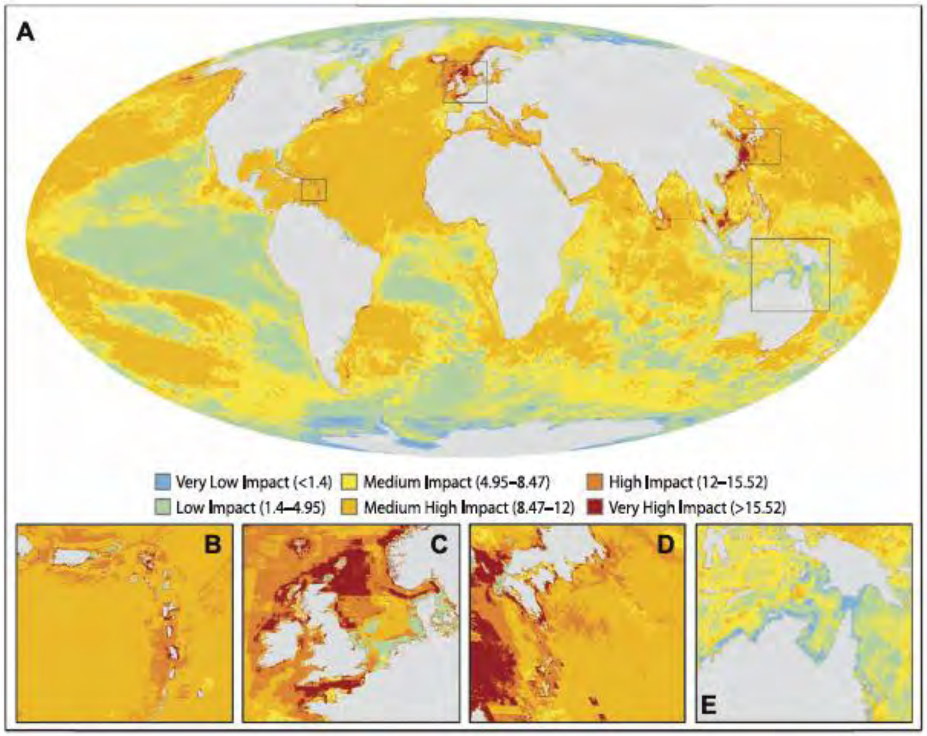
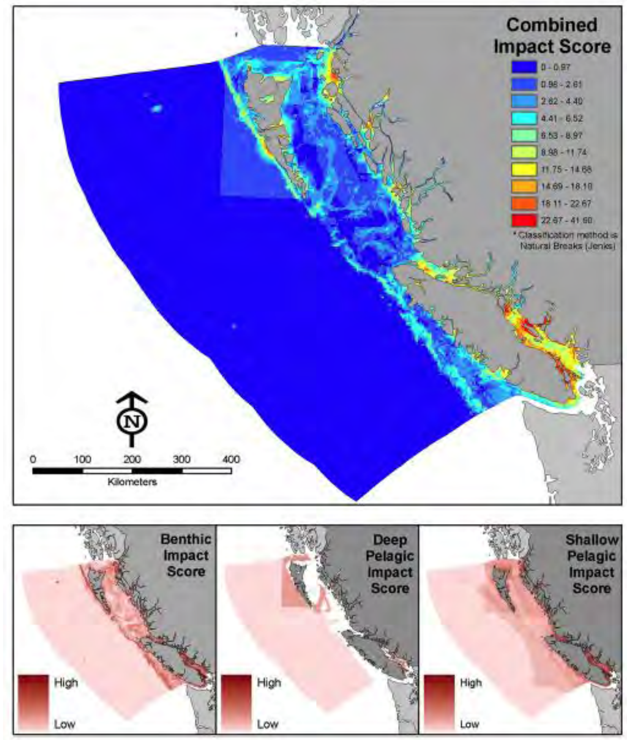
Background

Understanding cumulative impacts of multiple stressors is urgent issues for sustainable use of ecosystem serveices.



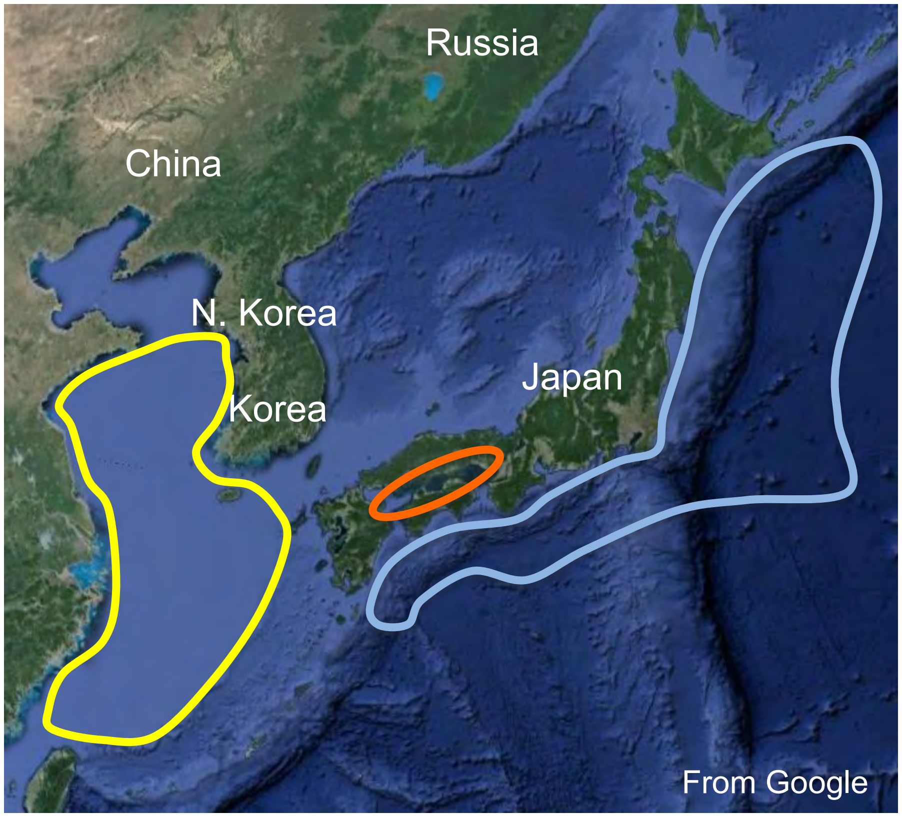
Halpern et al. (2008)



Ban et al. (2010)

PICES WG-28 has been trying to develop ecosystem indicators to characterize ecosystem responses to multiple stressors.

Waters comparing ecosystem responses in the western North Pacific



Shelf waters (4)
East China Sea
Yellow Sea

Inland waters (25)
Seto Inland Sea

Oceanic waters (7)
Kuroshio/Oyashio

Expert elicitation was adopted to evaluate ecosystem responses to multiple stressors in each ecosystem.

Habitats-stressors matrix

Impacts of human activities and natural stressors were evaluated using the habitat-stressors matrix.

Human activities

Natural stressors

Activities/Stressors	**Intertidal**	**Coastal**	**Shelf**	**Oceanic**
1. Pollution from land	1. Rocky	1. Seagrass	1. Soft bottom	1. Soft bottom slope
2. Coastal engineering	2. Beach	2. Kelp forest	2. Hard bottom	2. Hard bottom slope
3. Coastal development	3. Mud	3. Rocky reef	3. Ice	3. Soft bottom benthic
4. Direct human impact	4. Salt marsh	4. Suspension feeder reef	4. Pelagic water column	4. Seamount
5. Ecotourism		5. Sub-tidal soft bottom		5. Vents
6. Commercial activity				6. Soft bottom canyon
7. Aquaculture				7. Hard bottom canyon
8. Fishing – demersal				8. Deep pelagic water column
9. Fishing – pelagic				9. Upper pelagic water column
10. Fishing – illegal				
11. Offshore development				
12. Pollution from ocean				
13. Freshwater input				
14. Sediment input				
15. Nutrient input				
16. HABs				
17. Hypoxia				
18. Species invasion				
19. Sea level change				
20. Sea temperature				

Modified from Halpern et al. (2007)

Scoring vulnerabilities

For each cell, vulnerabilities were scored as spatial scale, frequency, functional impact, resistance, recovery time.

Weak ⟷ Strong

Vulnerabilities	**1**	**2**	**3**	**4**
Spatial scale	< 10 km^2	10-100 km^2	100-1000 km^2	> 1000 km^2
Frequency	> 5 yrs	1-5 yrs	Seasonal	Continuous
Functional impact	Species	Single trophic	Multitrophic	Community
Resistance	Positive impact	High	Moderate	Low
Recovery time	< 1 yr	1-10 yrs	10-100 yrs	> 100 yrs

For each vulnerability, certainty was scored as 4 levels.

Unsure ⟷ Sure

	1	**2**	**3**	**4**
Certainty	< 15 %	15–50 %	50–85 %	> 85 %

How to treat scores

Impacts (*I*) of stressors were evaluated using the weighted mean vulnerability (*v*) with certainty (*c*).

$$I = \sum v \cdot c \,/\, C_{total}$$

Habitat	Sub-habitat	Activity/Stressor	Spatial scale		Frequency		Trophic impact		Resistance to change		Recovery time		Impact: *I*
			v	*c*	*v*	*c*	*v*	*c*	*v*	*c*	*v*	*c*	
INTERTIDAL	beach	Fishing - pelagic	2	2	3	2	2	2	2	2	2	2	**2.10**
COASTAL	sub-tidal soft bottom	Nutrient inputs	2	2	2	2	2	2	2	2	2	2	**2.00**
COASTAL	sub-tidal soft bottom	Coastal engineering	3	4	3	4	4	3	4	4	3	3	**3.11**
SHELF	soft bottom	Freshwater input	4	3	3	3	3	3	3	2	3	2	**3.00**
SHELF	soft bottom	Sediment input	3	3	4	3	3	2	2	2	2	2	**2.50**
SHELF	soft bottom	Nutrient inputs	3	3	4	3	3	3	2	3	3	2	**2.64**
SHELF	soft bottom	Polution from land	3	3	4	3	3	3	3	3	3	2	**2.86**
SHELF	soft bottom	Fishing - demersal	4	3	4	3	4	3	4	3	3	3	**3.47**
SHELF	soft bottom	Fishing - pelagic	3	3	4	3	2	3	3	3	3	3	**2.67**
SHELF	soft bottom	Sea temperature	4	4	4	4	4	4	3	3	3	3	**3.22**
SHELF	soft bottom	HABs	2	3	3	3	3	3	3	3	3	3	**2.60**
SHELF	soft bottom	Hypoxia	2	2	3	2	3	3	4	2	3	2	**2.91**
SHELF	soft bottom	Offshore development	1	3	2	2	3	3	3	2	2	2	**2.17**
OCEANIC	soft bottom slope	Sea temperature	4	4	4	4	4	4	3	3	3	3	**3.22**

East China and Yellow Seas (Shelf water)

≦ 2.0 | 2.1-2.5 | 2.6-3.0 | 3.1-3.5

Activities/Stressors	Intertidal				Coastal				Shelf	
	Rocky	Mud	Salt marsh	Beach	Sea grass	Rocky reef	Suspention feeder reef	Sub-titdal soft bottom	Soft bottom	Pelagic water column
1. Pollution from land	2.8	2.8	2.5	2.5	2.5	2.8	2.5	2.8	2.9	2.9
2. Coastal engineering	3.5	3.5	3.3	3.3	3.3	3.5	3.3	3.3		
3. Coastal development	3.5	3.5	3.3	3.3	3.3	3.5	3.3	3.5		
8. Fishing - demersal									3.5	
9. Fishing - pelagic				2.1						3.1
11. Offshore development									2.1	
12. Pollution from ocean									3.1	3.1
13. Freshwater input	2.9	2.9	2.6	2.6	2.9	2.9	2.9	2.9	3.0	3.0
14. Sediment input									2.5	
15. Nutrient input	3.1	3.1	2.8	2.8	2.8	3.1	2.8	2.5	3.0	3.3
16. HABs									2.6	2.9
17. Hypoxia									3.2	
18. Species invasion	2.5	2.5	2.3	2.3	2.3	2.5	2.3	2.5		2.9
20. Sea temperature									3.2	3.2

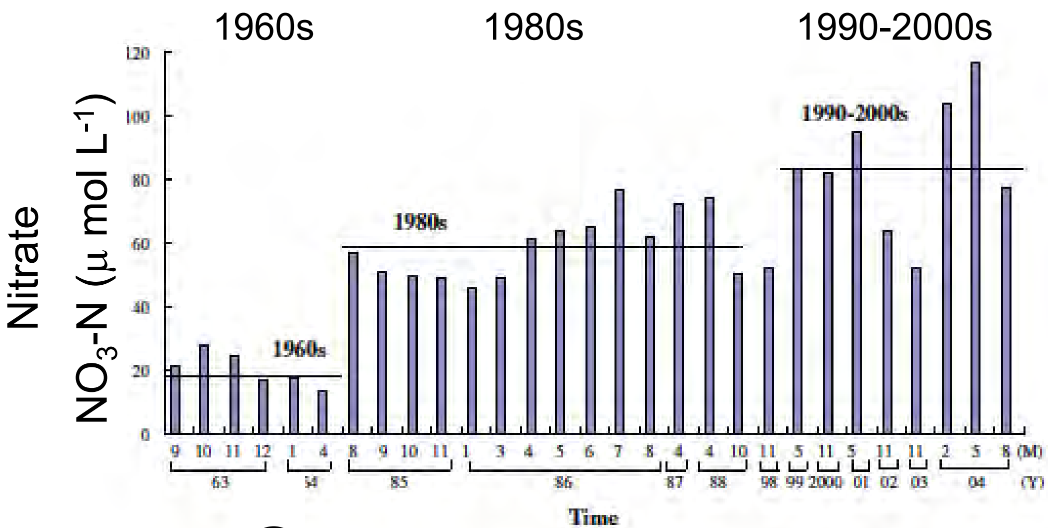
1. Coastal development strongly affects to the intertidal and coastal waters.
2. Pollution from land and nutrient input impact through intertidal to shelf waters.
3. Fishing and increasing temperature affects strongly to the shelf waters.

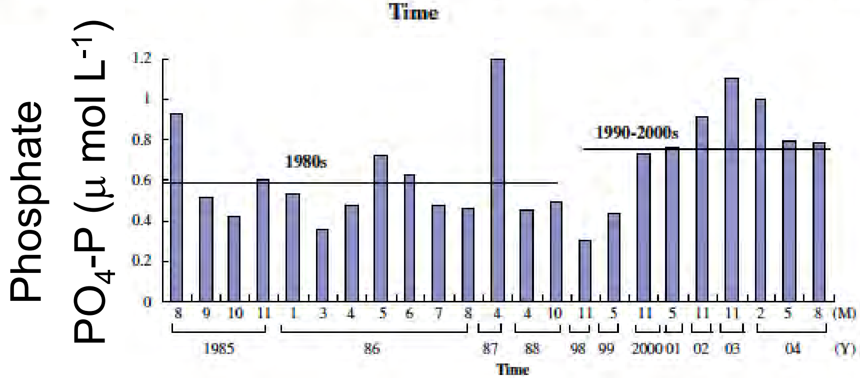
Reclamation in the Yellow Sea

Jiangsu Province

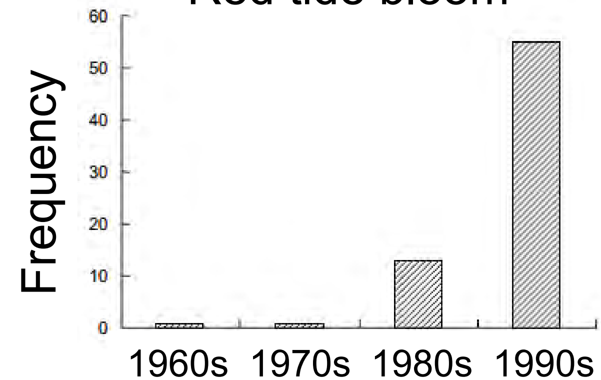
- Presently, over 5000 km^2 coastal wetlands, about one-fourth of China's total.
- Over 1300 km^2 coastal wetlands reclaimed over the past 15 years
- Plans to reclaim another 1800 km^2 by 2020

Nutrient increase and harmful algal bloom off the Changjang Estuary

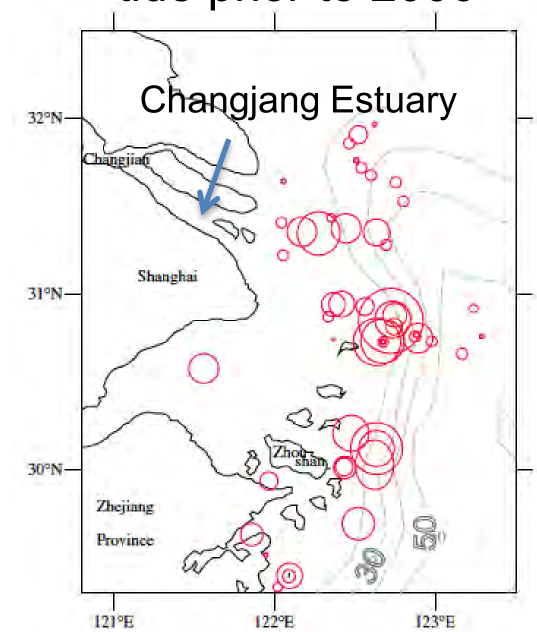




Red tide bloom



Occurrence of red tide prior to 2000

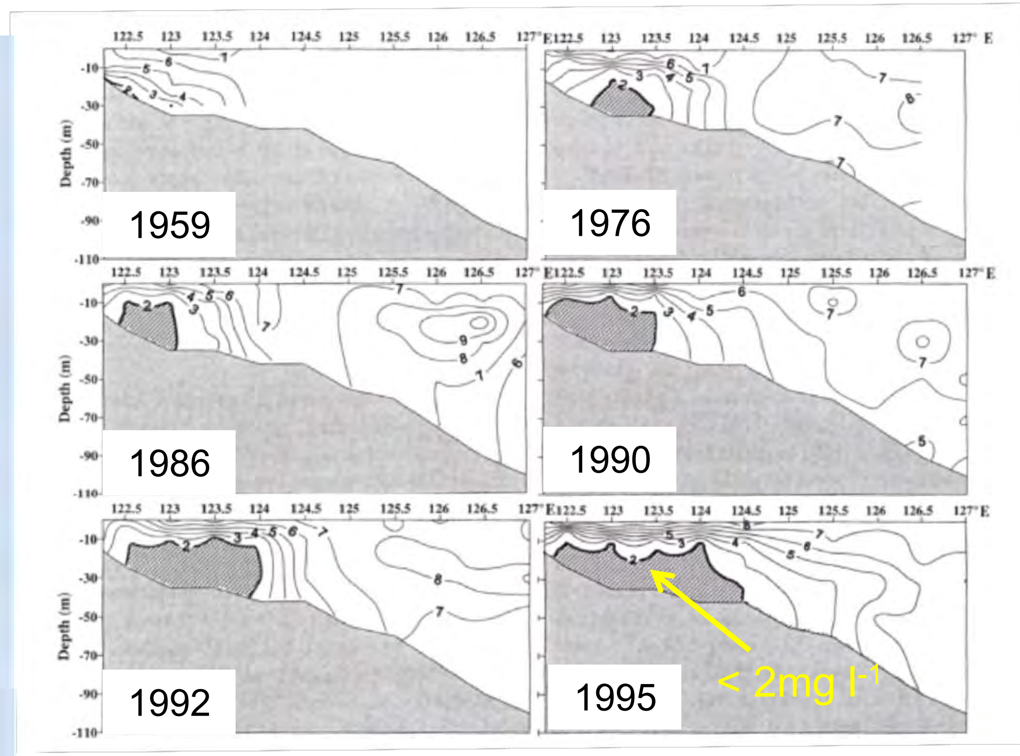


Frequency of red tide bloom increased with the increase in nutrient input after 1980s off the Changjang Estuary.

Zhou et al. (2008)

Hypoxia: dissolved oxygen off the Changjang Estuary in summer

Li and Zhang (2002)



Ning et al. (2011)

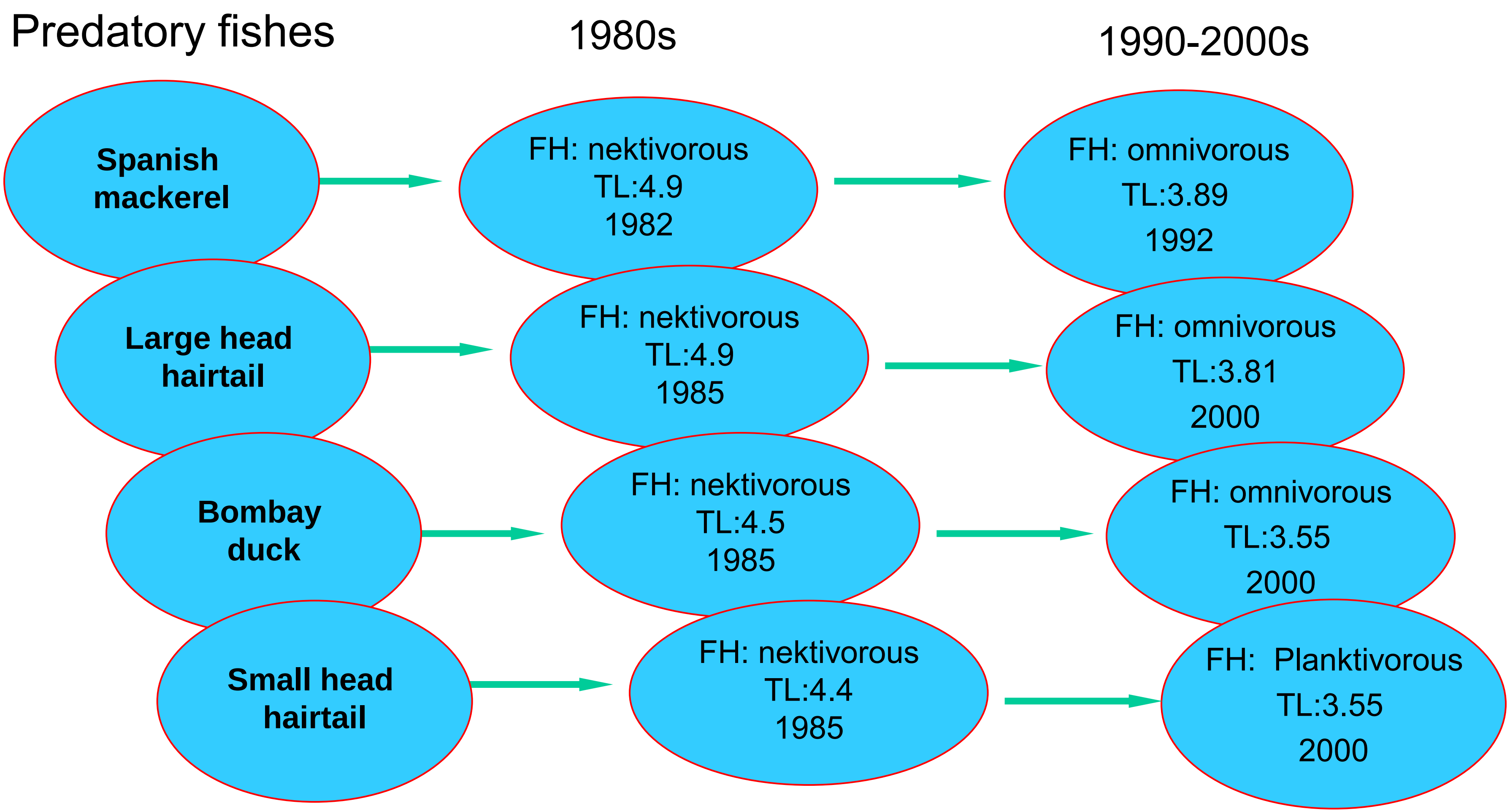
Potential causes –

Strong stratification in summer

Phytoplankton bloom

Taiwan Warm Current

Feeding habits of predatory fish species in the Yellow Sea during 1980-2000



Potential causes –

(Zhen et al. 2007)

Intensified fishing pressure (removal of high value & large fishes)

Alteration of prey fish species with changing climate (temperature)

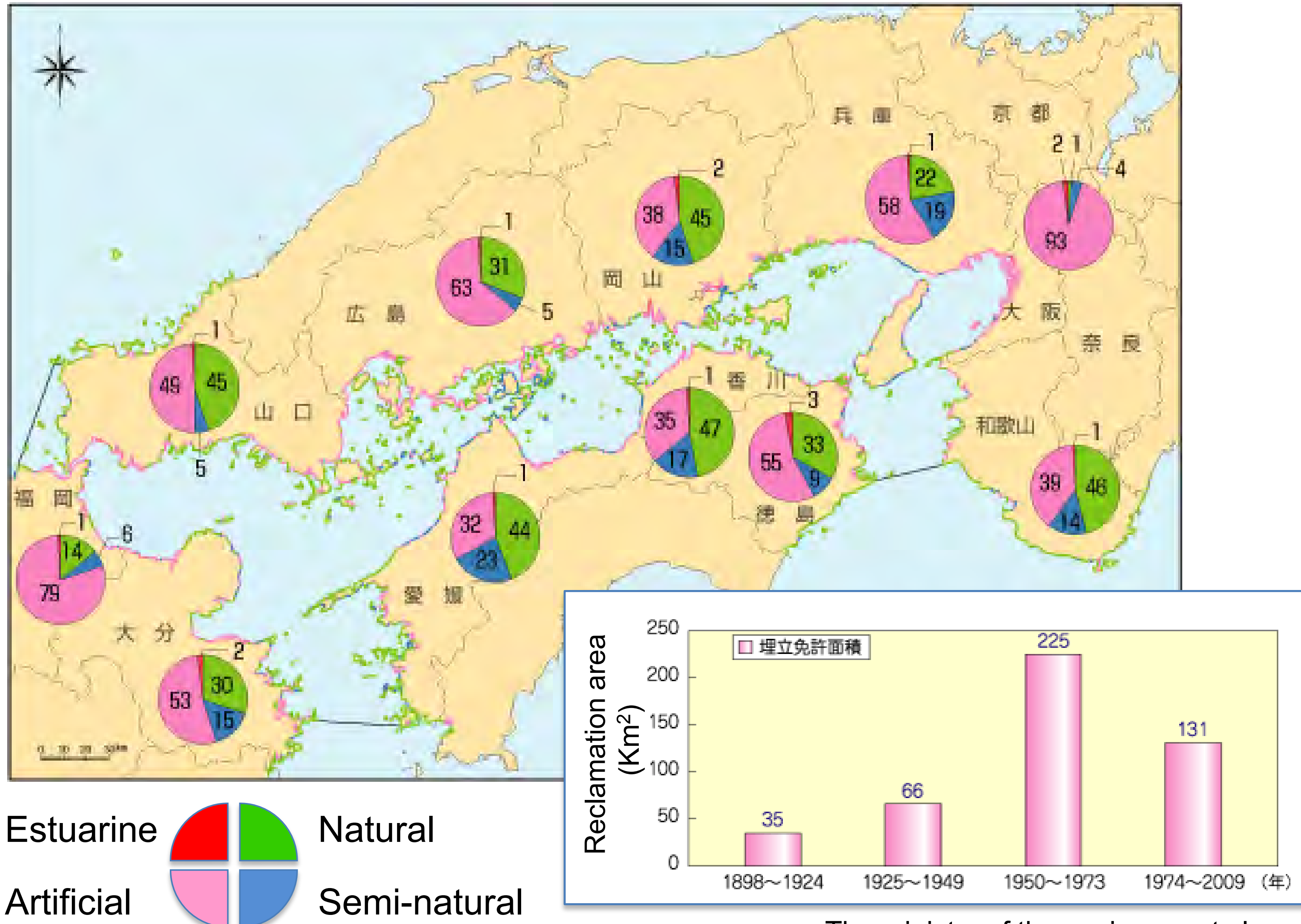
Seto Inland Sea (Inland water)

≦ 2.0 | 2.1-2.5 | 2.6-3.0 | 3.1-3.5 | 3.6-4.0

Activities/Stressors	Intertidal				Coastal					Shelf
	Rocky	Mud	Salt marsh	Beach	Seagrass	Kelp forest	Rocky reef	Suspention feeder reef	Sub-titdal soft bottom	Pelagic water column
1. Polution from land	2.8	3.0	3.0	2.9	2.9	3.0	2.8	3.0	3.1	3.4
2. Coastal enginnering	3.3	3.4	3.1	3.2	3.2	3.2	3.1	3.1	3.2	3.5
3. Coastal development	3.2	3.3	3.1	3.2	3.2	3.2	3.1	3.0	3.0	3.8
4. Direct human impact	3.1	3.2	3.0	3.1	3.0	3.0	2.9	3.0	3.0	
5. Ecotourism	2.3	2.4	2.3	2.4	2.3	2.3	2.3		2.4	
6. Commertial activity	3.1	3.1	3.0	2.9	2.9	2.9	3.0	3.0	3.1	
7. Aquaculture		3.1	3.0		3.0	3.2	2.9	3.1	3.1	2.8
8. Fishing - demersal	2.3	2.9	2.9		2.8	2.8	2.9	3.2	3.2	3.7
9. Fishing - pelagic		3.0	3.0		2.2	2.2	2.0	2.9	2.7	3.6
10. Fishing - illecal	2.2	2.5	2.5			2.3	1.7	3.0	3.1	3.1
11. Offshore development		3.0	3.0	3.0	2.8	2.8	3.0	2.9	2.6	
12. Polution from ocean	3.0	3.2	3.1	3.0	3.0	2.8	2.7	2.8	2.8	
13. Freshwater input	2.8	2.8	2.7	2.8	2.7	2.5	2.4	2.7	2.5	3.5
14. Sediment input	3.0	2.9	2.8	2.9	2.8	2.9	2.2	2.7	2.7	2.8
15. Nutrient input	3.4	3.2	3.1	3.3	3.0	3.0	3.0	3.0	3.0	2.9
16. HABs	2.5	2.7	2.7	2.4	2.6	2.8	2.8	3.0	3.0	2.4
17. Hypoxia	3.0	2.9	2.8	2.7	2.7	2.8	2.7	3.0	3.0	2.8
18. Species invasion	2.9	2.9	2.9	2.9	2.9	3.0	3.0	2.8	2.8	2.7
19. Sea level change	3.2	3.1	3.1	3.2	3.3	3.1	3.0	3.1	2.9	2.9
20. Sea temperature					3.4					3.5

1. Coastal development and engineering affects to the ecosystem directly.
2. Pollution from ocean and nutrient input affects to water quality.
3. Sea level change and increasing temperature affect to the entire waters.

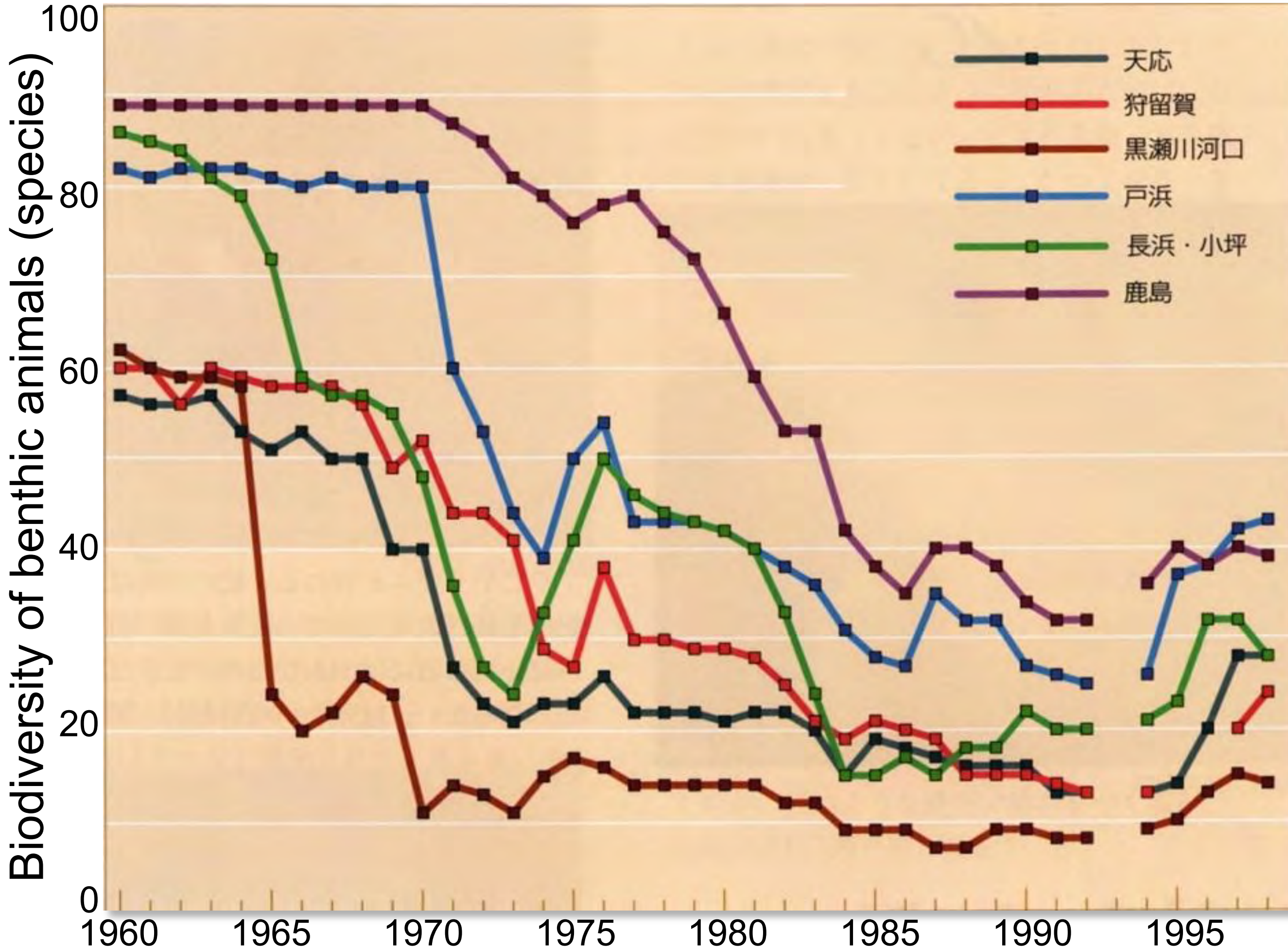
Coastal development reduced natural shore lines



The ministry of the environment, Japan

Trends in biodiversity of benthic animal

Seto Inland Sea



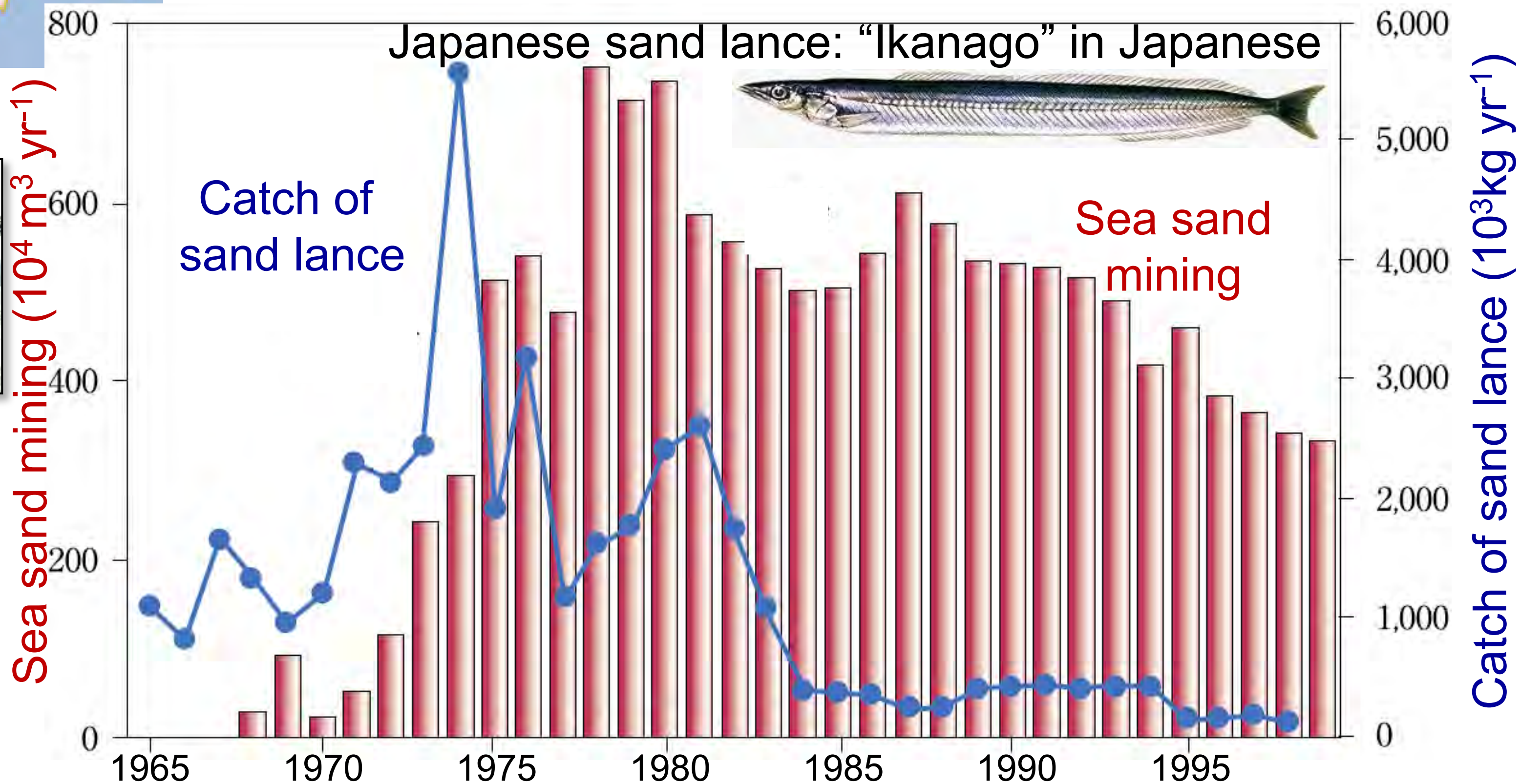
Interannual changes in the biodiversity of benthic animal at 6 stations around Kure City in Hiroshima prefecture.

Fujioka (2000)

From the mid ‘60s to mid ’90s, the biodiversity of benthic animals had been decreased by environmental degradation.
After the mid ’90, it has been recovered with environmental reclamation.

Decrease in the catch of sand lance associated with the sea sand mining

Seto Inland Sea

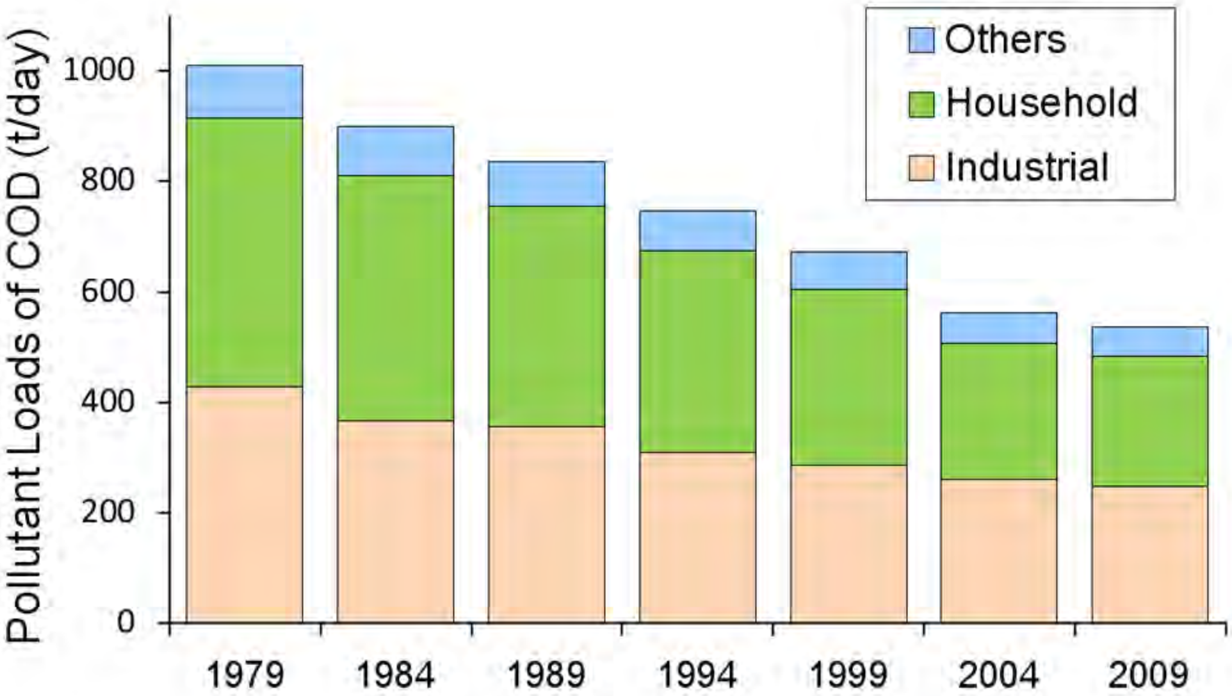


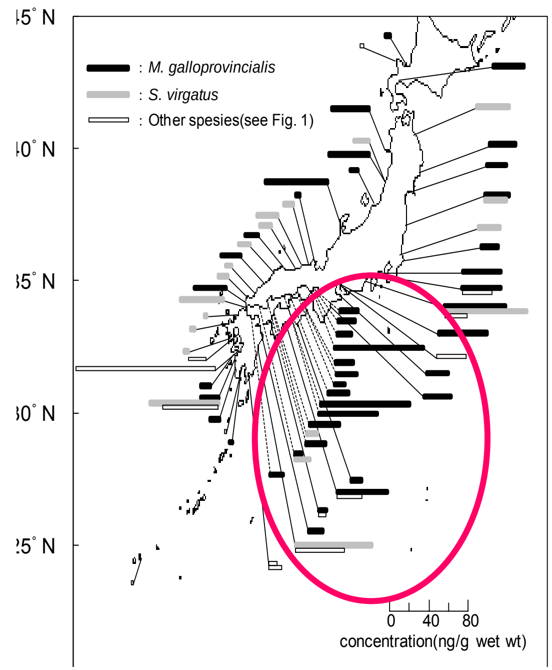
Interannual changes in the sea sand mining and the catch of sand lance in Okayama prefecture.

Uye (2007)

The catch of the sand lance decreased with the sea sand mining from the sand bank in the Seto Inland Sea. The more high-value fishes (e.g. sea bream, Japanese seaperch etc.) also decreased with decrease of their prey, sand lance.

Pollutant load into the Seto Inland Sea





Pollutant load into the Seto Inland Sea has decreased continuously since the end of 1970s.

The ministry of the environment, Japan

Distribution of polycyclic aromatic hydrocarbons (PAHs) in the bivalves collected from the coastal waters of the Inland Sea (red circle) shows that pollution still impacted the coastal ecosystems.

Tanaka and Oniduka (2010)

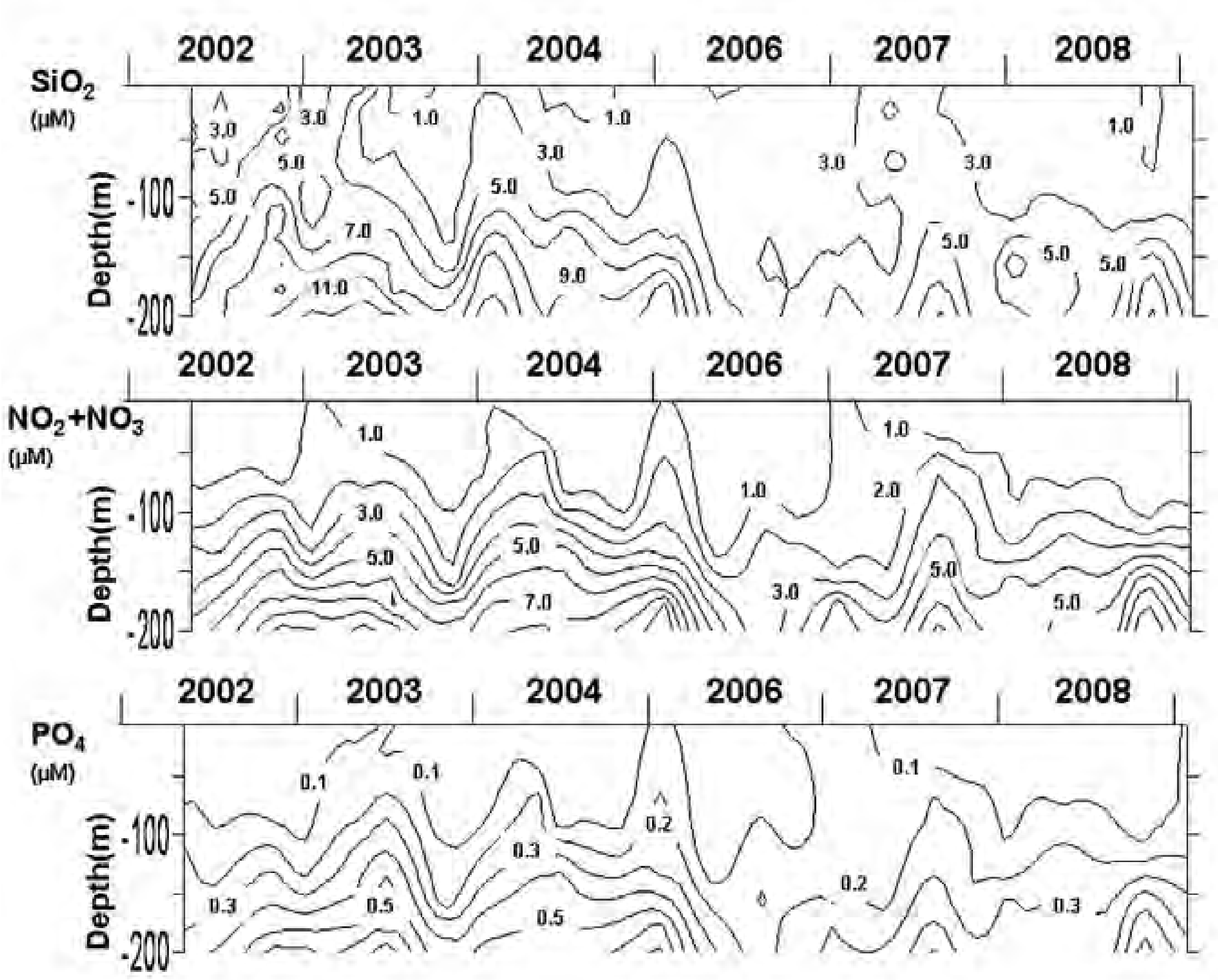
Kuroshio/Oyashio (Oceanic waters)

□ ≦ 2.0 | 2.1-2.5 | 2.6-3.0 | 3.1-3.5

Activities/Stressors	Shelf		Oceanic
	Pelagic water column	Soft bottom	Upper pelagic water column
8. Fishing - demersal		3.2	2.3
9. Fishing - pelagic	3.3		3.2
15. Nutrient input	3.2		2.9
17. Hypoxia	3.0	3.0	
19. Sea level change			3.2
20. Sea temperature	3.2	3.3	3.1

1. Increasing temperature affects to the entire waters.
2. Decreasing DO and nutrient concentrations are observed

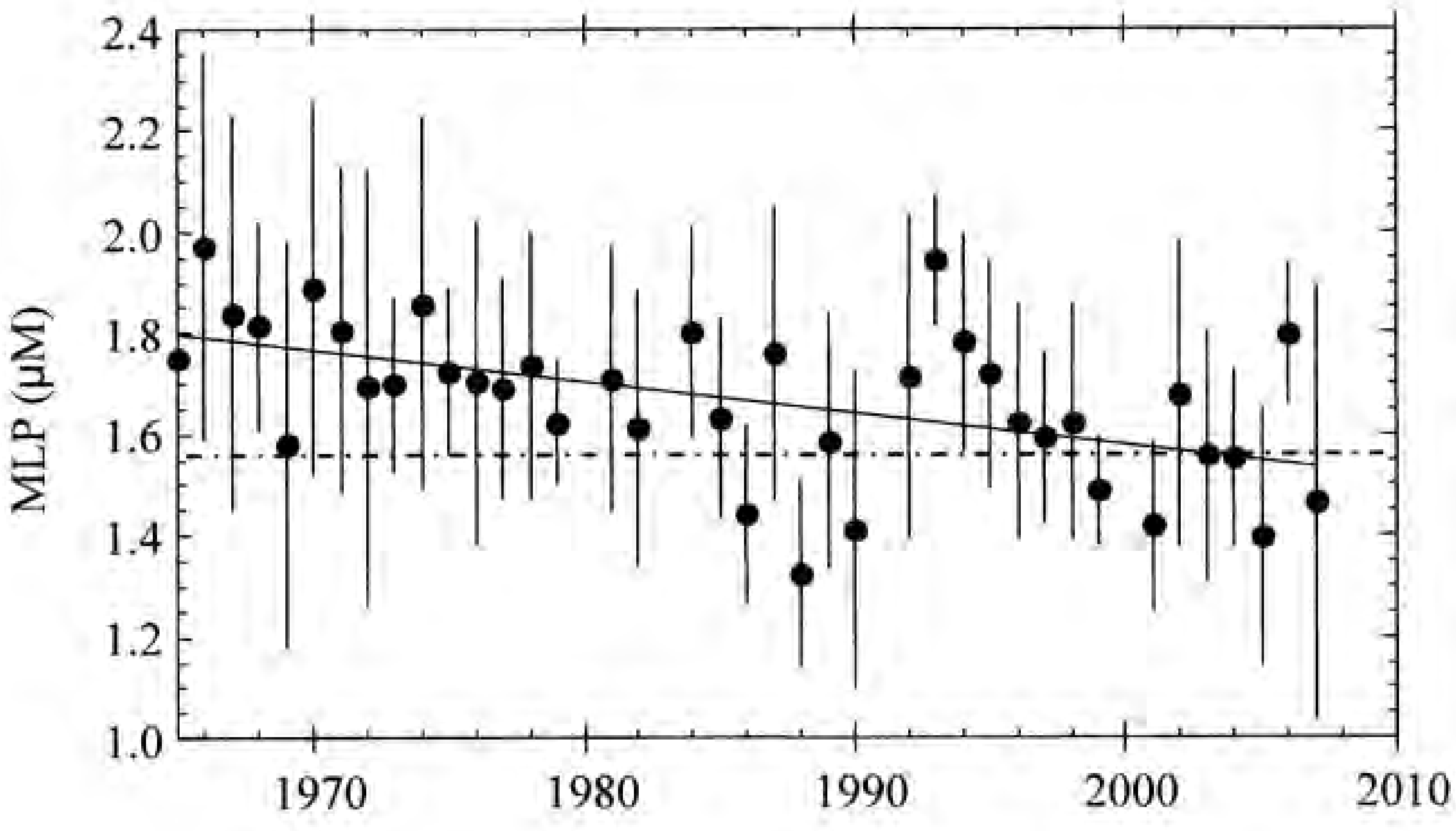
Decrease in nutrient concentration (Kuroshio)



Decreasing trend of nutrient concentrations, possibly due to the rise in water temperature (increasing stratification)

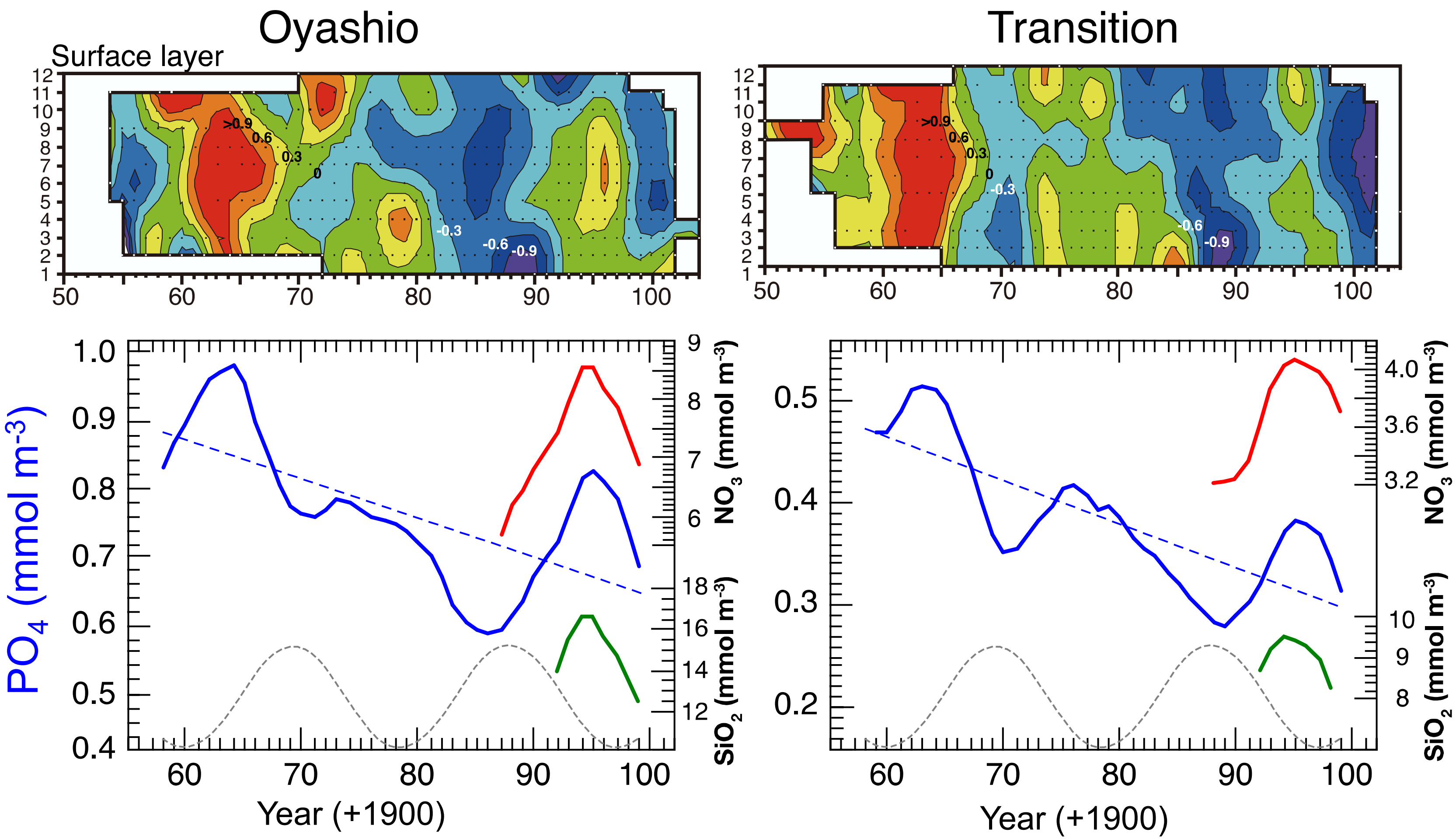
Sugisaki et al. 2010, PICES Special Publication

Decrease in nutrient concentration (Oyashio)



Decreasing trend of nutrient concentration within mixed layer, causing the decrease in net community production (Ono et al. 2002)

Decadal variability in nutrient concentrations



Besides the decreasing trend in surface phosphate concentration, large-amplitude decadal fluctuation was observed, which was synchronous to 18.6-year nodal-tidal cycle.

Tadokoro et al. (2009)

Main stressors impacting ecosystems in the shelf, inland and oceanic waters

Activities/Stressors	ECS/YS	SETO	K/O
1. Polution from land	2.7	3.0	
2. Coastal enginnering	3.4	3.2	
3. Coastal development	3.4	3.2	
4. Direct human impact		3.0	
5. Ecotourism		2.3	
6. Commertial activity		3.0	
7. Aquaculture		3.0	
8. Fishing - demersal	3.5	2.9	2.8
9. Fishing - pelagic	2.6	2.7	3.3
10. Fishing - illegal		2.6	
11. Offshore development	2.1	2.9	
12. Polution from ocean	3.1	2.9	
13. Freshwater input	2.9	2.7	
14. Sediment input	2.5	2.8	
15. Nutrient input	2.9	3.1	3.0
16. HABs	2.8	2.7	
17. Hypoxia	3.2	2.8	3.0
18. Species invasion	2.5	2.9	
19. Sea level change		3.1	3.2
20. Sea temperature	3.2	3.5	3.2

Coastal development and engineering have strong impacts to the ECS/YS and the SETO.

Demersal and pelagic fishing impact to the ECS/YS and the K/O, respectively.

Nutrient input has resulted in HABs and Hypoxia in summer.

Increasing sea temperature affects strongly to all 3 ecosystems.

Conclusions

- Expert elicitation methods using the habitat-stressor matrix were applied to evaluate ecosystem responses to multiple stressors.
- Coastal development and engineering have strong impacts to the shelf and inland waters.
- Excessive input of nutrient causes harmful algal bloom and hypoxia in summer in the shelf water.
- Increasing temperature impact strongly in the 3 ecosystems.
- Need more responses for evaluation in the shelf and oceanic waters.