Climate effect on spatial-temporal variation of demersal fish assemblages in the Tsushima Current region of Japan Sea

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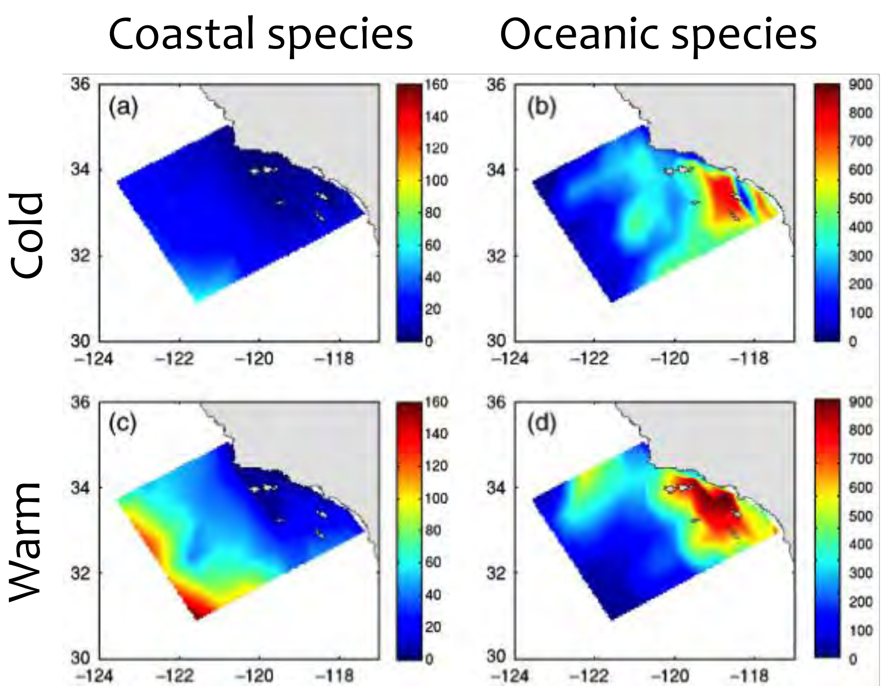
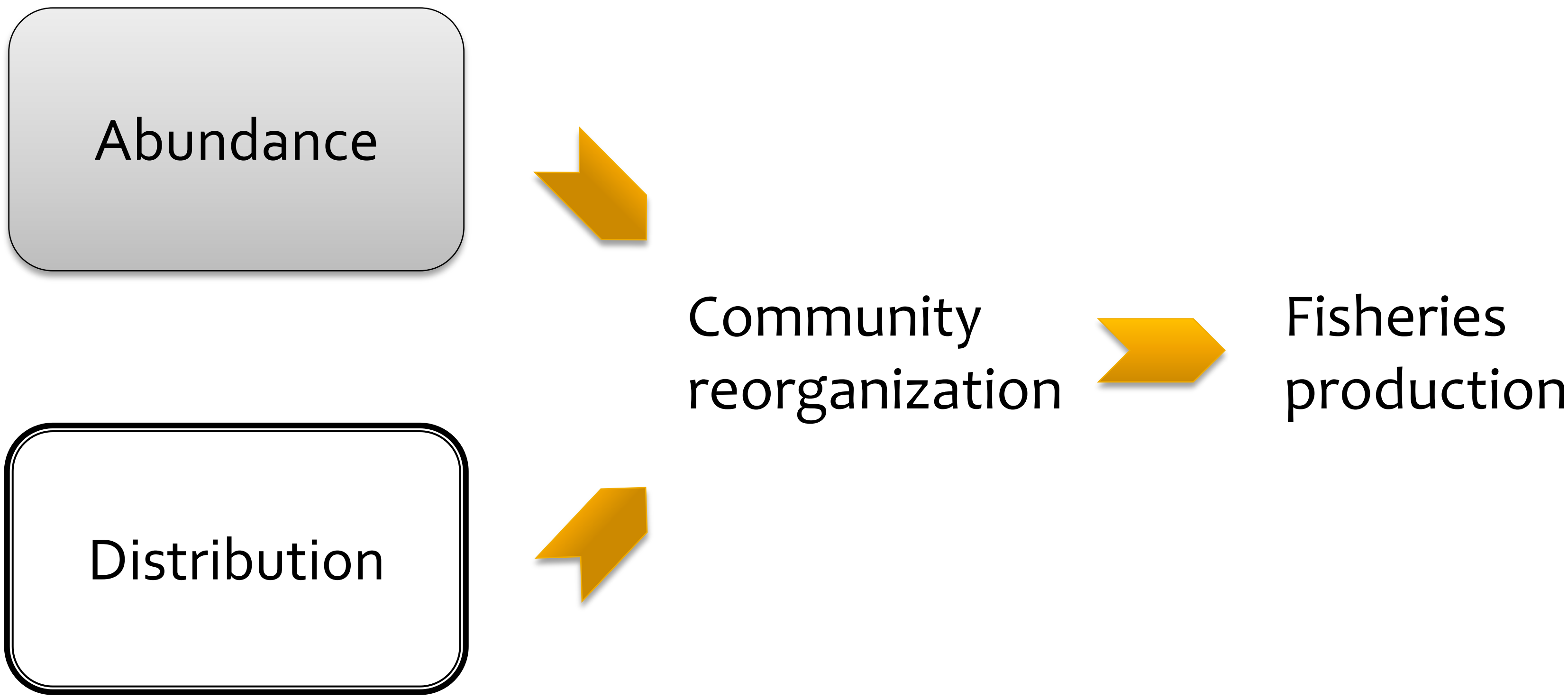
Climate effects on the marine population



CalCOFI fish larvae
Hsieh *et al.*, 2009

- Climate change has significant influences on phenology, geographical distribution and abundance of marine populations
  (Stenseth *et al.*, 2002; Walther 2010; Doney *et al.*, 2012; Poloczanska *et al.*, 2013)

From climate effect to fisheries



MacNeil *et al.*, 2010

Why species response differently?

Life history traits

- Age-at-maturation, maximum length
  - Species with same age-at-maturation would fluctuate synchronously (Hsieh *et al.*, 2005)
  - Fast growing, short life-span species are more likely to shift poleward (Perry *et al.*, 2005)

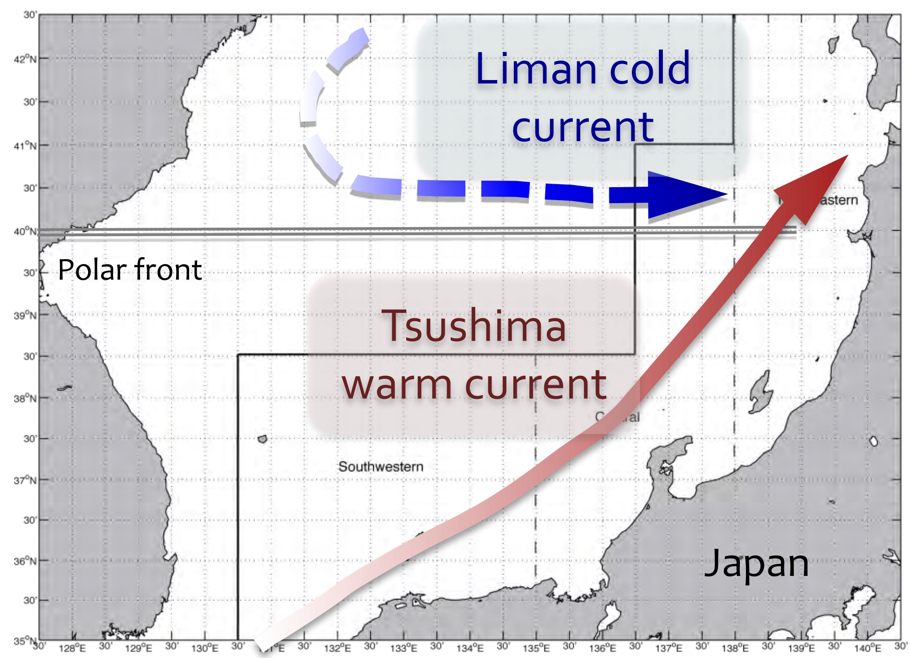
Ecological traits

- Biogeography
  - Southern and northern stock show contrasting responses to warming (Nye *et al.*, 2009)

Japan Sea Ecosystem

- A semi-closed marginal sea influenced by basin-scale climatological event (Naganuma 2000; Watanabe *et al.*, 2003)
  - Shift of plankton biomass and PDO (Chiba *et al.*, 2005)
  - Decadal variation of fish abundance (Tian, 2008)

No systematic study on distributional change of demersal species



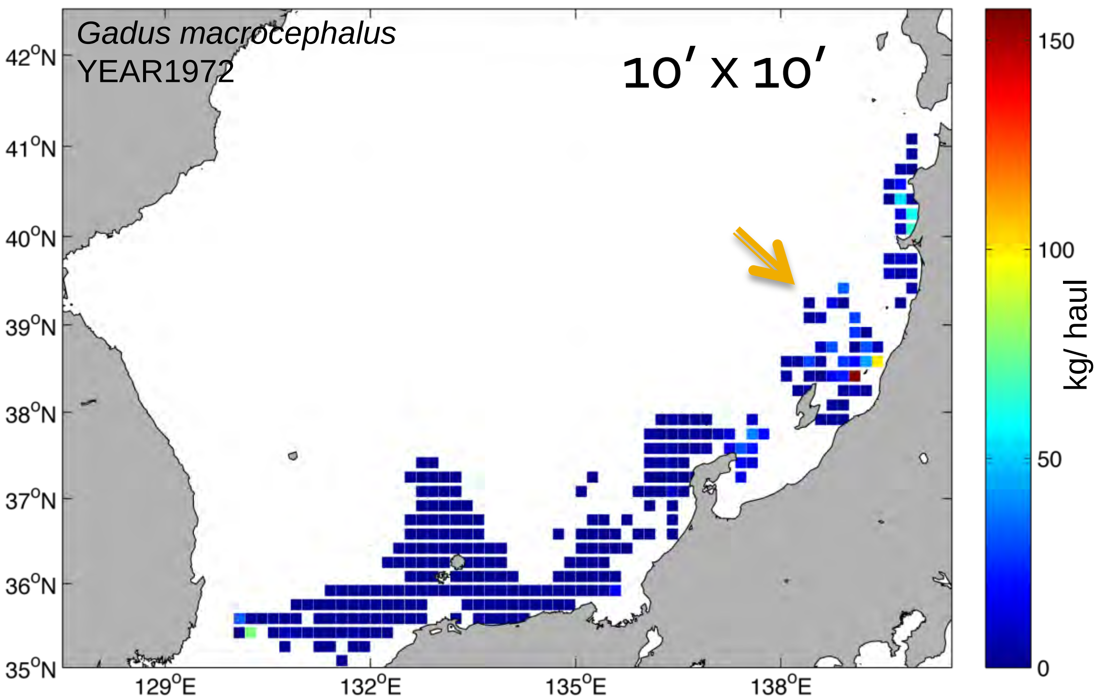
Objectives

- Investigate the climate effects on the temporal variation of abundance and distribution of the demersal fish assemblage in Tsushima current region of Japan Sea

- How well can the differences ecological and life history traits explain the species' responses to climate variability?

Demersal fish assemblage

- Japan Sea offshore bottom trawl dataset (JSOBT)
  - Catch & effort of single trawler from 1972 to 2002



Annual CPUE map

Average across spawning seasons

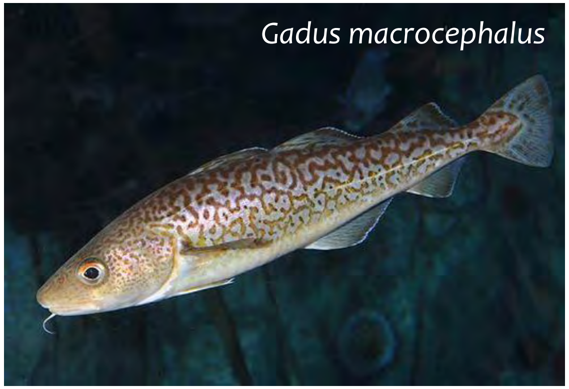
Co-present of cold and warm water species
(Nishimura, 1966)

Life history traits-
A_m : age-at-maturation
L_{inf}: asymptotic length

Species	Geographic affinity	Depth (m)	A_m	L_{inf}	Spawning season
Gadus macrocephalus	Cold water	200-300	4	91.3	Jan-Mar
Theragra chalcogramma	Cold water	100-500	3	56.1	Dec-Mar
Pleurogrammus azonus	Cold water	<200	2	43.5	Sep-Nov
Arctoscopus japonicus	Cold water	300-500	2	27.8	Dec-Mar
Squalus acanthias	Cold water	150-180	10	124.0	Feb-May
Glyptocephalus stelleri	Cold water	200-300	2	58.9	Jan-Apr
Hippoglossoides dubius	Cold water	150-500	5	55.8	Feb-Apr
Pleuronectes herzensteini	Cold water	30-130	2	28.2	Feb-May
Microstomus achne	Cold water	50-400	3	71.5	Feb-Apr
Pandalus eous	Cold water	200-950	4	3.5	Feb-Apr
Hippoglossoides pinetorum	Warm water	150-190	2	37.0	Jan-Mar
Eopsetta grigorjewi	Warm water	<140	2	40.8	Feb-Mar
Tanakius kitaharai	Warm water	80-150	2	28.0	Dec-Jan
Glossanodon semifasciatus	Warm water	<200	1	25.5	Jan-Sep
Paralichthys olivaceus	Warm water	<150	2	80.7	Mar-Jul
Pagrus major	Warm water	<100	3	54.4	Apr-Jul
Evynnis japonica	Warm water	30-130	2	34.0	Jul-Sep
Dentex tumifrons	Warm water	<200	2	41.5	Sep-Nov
Lepidotrigla microptera	Warm water	70-140	1	30	Feb-Jun
Trichiurus japonicus	Warm water	20-140	1	65.8	Apr-Oct

Target species of single trawler

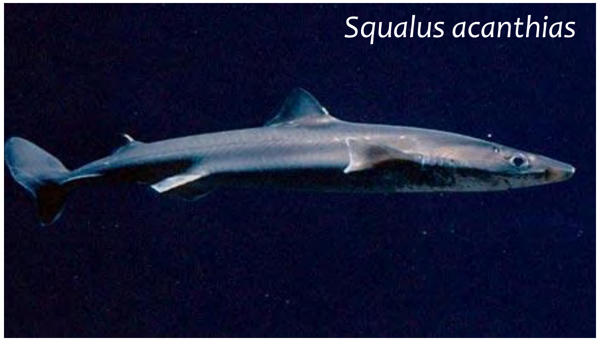
Cold water species



http:///overvieweol.org/pages/206691

Pleuronectes herzensteini

http://www.weblio.jp/content/Pleuronectes+herzensteinii

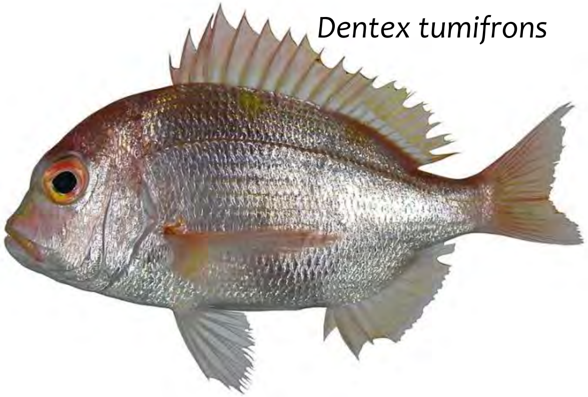


http://www.montereybayaquarium.org/

Warm water species

http://www.honda.co.jp/fishing/picture-book/hirame/images/092.jpg

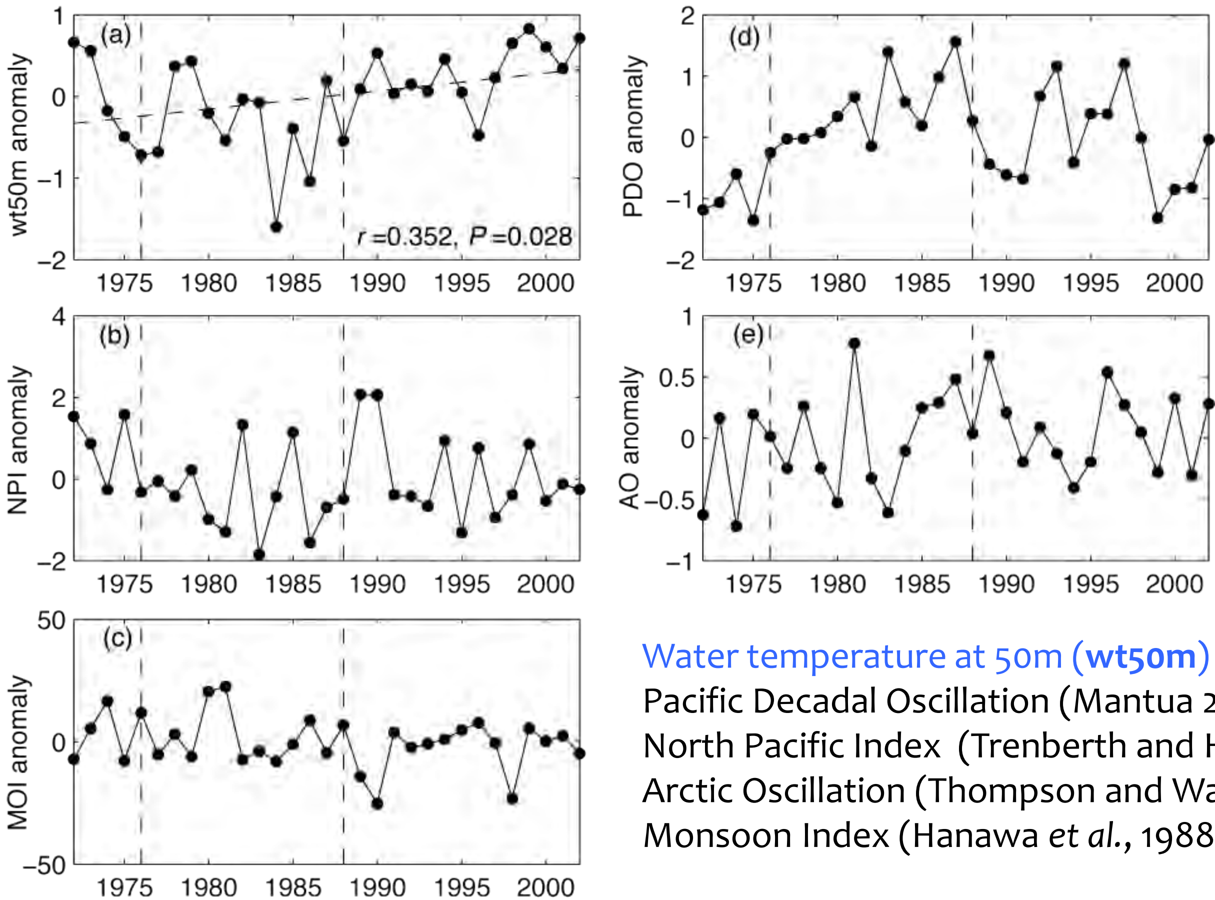
Dentex tumifrons



http://content.teldap.tw/main/dc_detail.php?dc_id=2446281

http://www.jfa.maff.go.jp/sakaiminato/kantoku/photo_fish.html

Environmental variables



Cold period: 1976/77 - 1988/89
Warm period: 1988/89 - 2002

Water temperature at 50m (**wt50m**)
Pacific Decadal Oscillation (Mantua 2002)
North Pacific Index (Trenberth and Hurrell 1994)
Arctic Oscillation (Thompson and Wallace 2000)
Monsoon Index (Hanawa *et al.*, 1988)

Spatial distribution of single trawl catches and efforts

	Annual mean abundance (**CPUE**)	Annual distribution center/ boundary
Interannual	Regression: Annual abundance vs Environmental variables	Regression: Annual center/ boundary vs Environmental variables
Decadal	Randomization test: Comparing abundances in the cold and warm periods	Randomization test: Comparing centroids in the cold and warm periods

1. Interannual
2. Decadal
3. Both-scale

Logistic regression (**shift/non-shift**)
v.s.
Ecological/Life history traits

Distribution and abundance index

Abundance

- Average of the CPUE value from all the non-zero fishing areas on the annual map

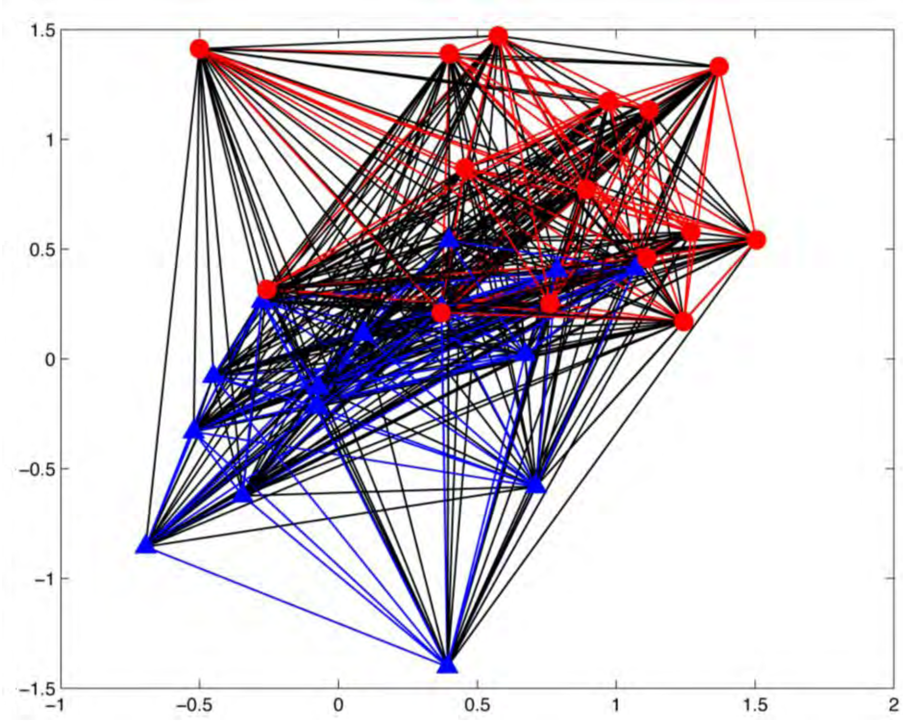
Distribution

- Center: Mean and median latitude
- Boundary: Max/ Min latitude
  - Northern (max. lat) - warm water species
  - Southern (min. lat) - cold water species

Regression analysis with environmental variables

- Use Estimated General Least Square (Ives & Zhu, 2006) to account for serial dependency in the time-series
  - Consider 1-year and 3-year lagged environmental effect
  - When significant correlation exist between abundance and distributional index, we control the abundance for partial regression

Decadal-scale shift in distribution



Significant test by randomization
T = Within period /Betw. period

(Hsieh *et al.*, 2008)

Result

- Environmental variations
- Change in geographical distribution
- Change in abundance

Environmental variations

- Complex interaction between atmospheric forcing and local water temperature (wt50m)

	wt50m	PDO	NPI	AO
PDO	-0.367*			
NPI	0.270	-0.661*		
AO	-0.105	0.203	0.063	
MOI	-0302	0.108	-0.473*	-0.076

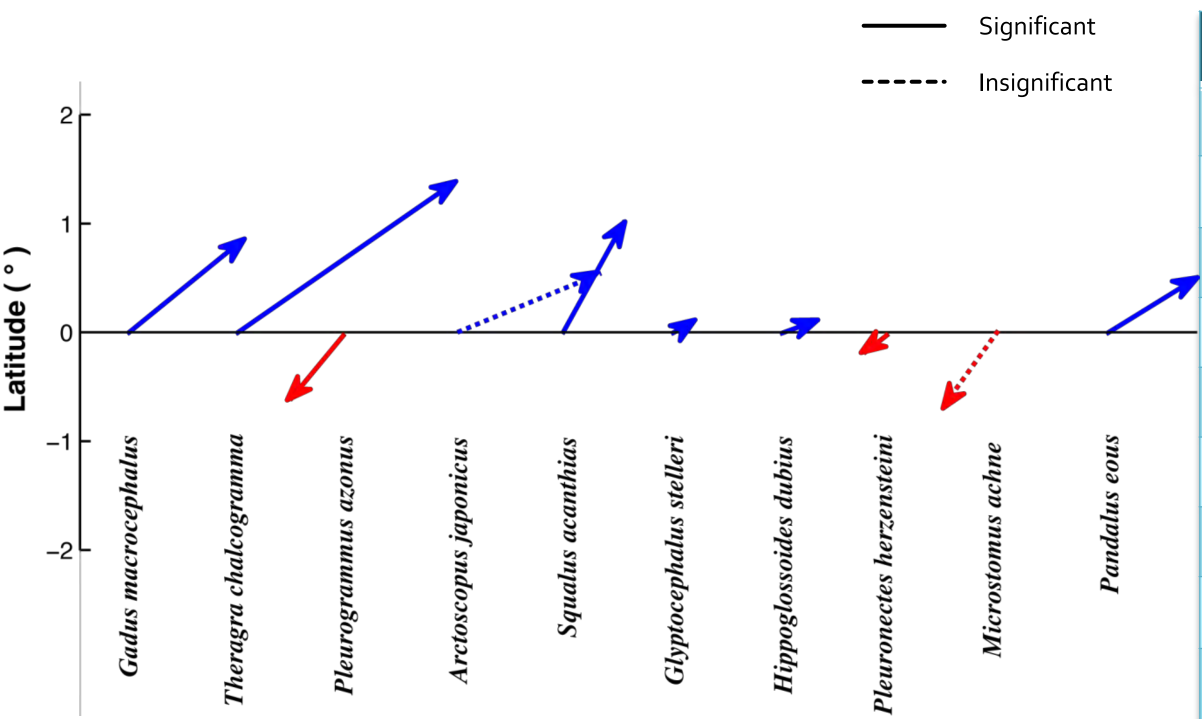
Species	Geographic affinity	MeanLAT	MedLAT	Boundary	Shift in Distribution	Abundance	Shift in Abundance
Gadus macrocephalus	Cold water			+NPI (3)	+	+AO (1)	
Theragra chalcogramma	Cold water		-MOI		+	-AO	
Pleurogrammus azonus	Cold water	-AO	-AO		+	-wt50m	-35.2524
Arctoscopus japonicus	Cold water		-PDO	+NPI		-PDO	-17.7438
Squalus acanthias	Cold water	+wt50m	+wt50m	+NPI	+	-PDO (1)	-20.5291
Glyptocephalus stelleri	Cold water		-wt50m	+AO (3)			-4.2561
Hippoglossoides dubius	Cold water	-PDO		+PDO (1)	+	-PDO (1)	-11.7849
Pleuronectes herzensteini	Cold water			-wt50m (1)		-PDO	-0.9105
Pleuronecidae (*Microstomus achne*)	Cold water	-wt50m	-wt50m	wt50m (1)	+	NPI (1)	-1.6959
Pandalus eous	Cold water	-PDO	wt50m (3)	-MOI	+	-AO (1)	
Hippoglossoides pinetorum	Warm water				+		
Eopsetta grigorjewi	Warm water			+AO		PDO (1)	
Tanakius kitaharai	Warm water					+MOI	
Glossanodon semifasciatus	Warm water	+MOI			+	+MOI (3)	
Paralichthys olivaceus	Warm water	-NPI (1)	-NPI (1)		+	-NPI (3)	-0.8323
Pagrus major	Warm water	+NPI (1)	+wt50m	+PDO (3)		+wt50m	0.5094
Evynnis japonica	Warm water				+	+AO (3)	1.5133
Dentex tumifrons	Warm water	+wt50m (1)	+NPI (1)	-wt50m	+	+MOI (1)	0.9436
Lepidotrigla microptera	Warm water	+wt50m (1)	-NPI	-wt50m	+	+MOI (3)	
Trichiurus japonicus	Warm water				+		-1.0378

Distribution

All cold water species were in relation with the environmental variable

Over 55% of species has significant shift from cold to warm period

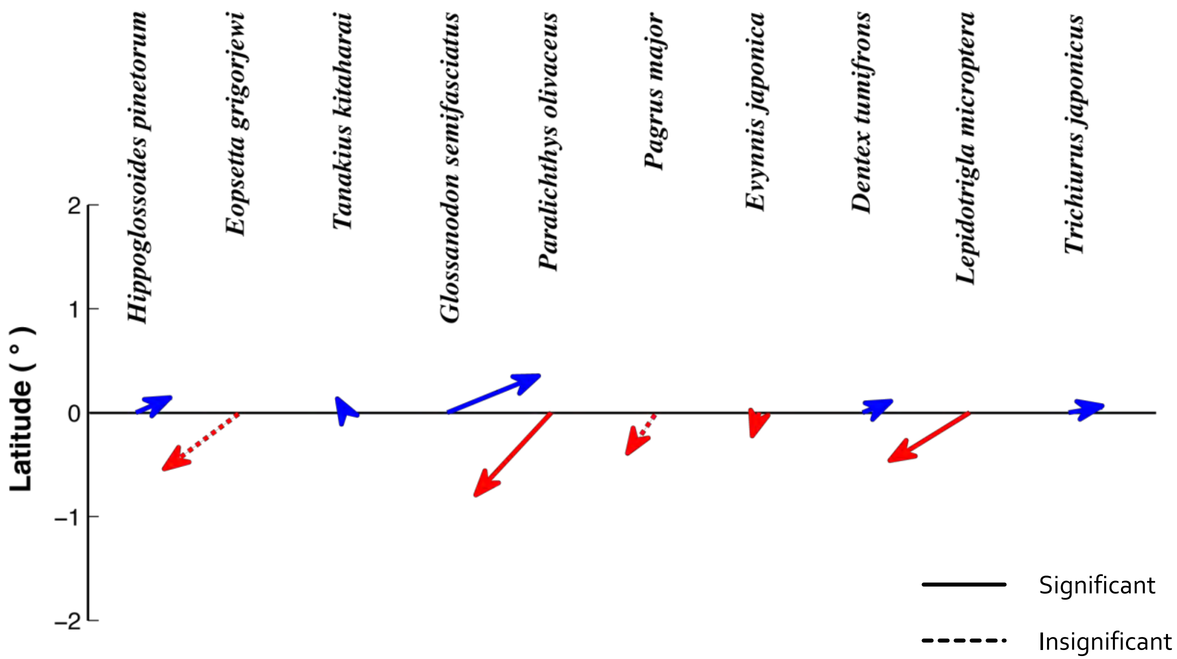
Cold water species



Cold-warm period

Species	MeanLAT	MedLAT	Boundary
Gadus macrocephalus			+NPI (3)
Theragra chalcogramma		-MOI	
Pleurogrammus azonus	-AO	-AO	
Arctoscopus japonicus		-PDO	+NPI
Squalus acanthias	+wt50m	+wt50m	+NPI
Glyptocephalus stelleri		-wt50m	+AO (3)
Hippoglossoides dubius	-PDO		+PDO (1)
Pleuronectes herzensteini			-wt50m (1)
Microstomus achne	-wt50m	-wt50m	wt50m (1)
Pandalus eous	-PDO	wt50m (3)	-MOI

Warm water species



Cold-warm period

Species	MeanLAT	MedLAT	Boundary
Hippoglossoides pinetorum			
Eopsetta grigorjewi			+AO
Tanakius kitaharai			
Glossanodon semifasciatus	+MOI		
Paralichthys olivaceus	-NPI (1)	-NPI (1)	
Pagrus major	+NPI (1)	+wt50m	+PDO (3)
Evynnis japonica			
Dentex tumifrons	+wt50m (1)	+NPI (1)	-wt50m
Lepidotrigla microptera	+wt50m (1)	-NPI	-wt50m
Trichiurus japonicus			

Effect from ecological and life history traits

	Interannual			Decadal			Both		
	AIC	b	p value	AIC	b	p value	AIC	b	p value
Affinity	17.460	-19.161	0.033	27.675	0.154	0.876	28.917	-1.099	0.245
A_m	21.190	1.061	0.287	26.943	0.29	0.438	27.459	0.658	0.152
L_{inf}	22.323	0.032	0.317	26.943	0.045	0.134	26.673	0.044	0.078

Affinity: cold/warm water
A_m: age at maturation
L_{inf}: asymptotic length

Physiological basis of geographical affinity

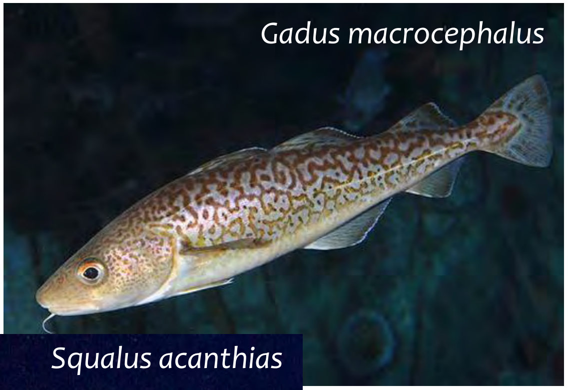
- Thermal tolerance limit
  - Generally narrower in Cold-water species with subarctic origin than warm-water species
    (Pörtner and Peck, 2010)

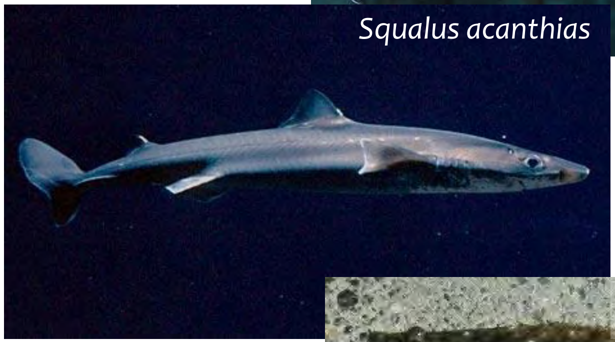
	Interannual		
	AIC	b	p value
Affinity	17.460	-19.161	0.033
A_m	21.190	1.061	0.287
L_{inf}	22.323	0.032	0.317

Potential fishing impact indicated by body length

- Large species are mostly important fisheries targets

	Both		
	AIC	b	p value
Affinity	28.917	-1.099	0.245
A_m	27.459	0.658	0.152
L_{inf}	26.673	0.044	0.078





Species interaction

- Habitat quantity is important for juvenile settlement of demersal species (Gibson *et al.*, 1994; Van der Veer 2000)
- Such interactions may play a role in mediating the response to climate change

	Distribution
Interannual	Geographical affinity
Decadal	**x**
Interannual + Decadal	Asymptotic length

Shift in abundance

Cold water

Species	Decadal (Warm-Cold)	Interannual
Gadus macrocephalus	-0.9943	AO (1)
Theragra chalcogramma	-1.7222	-AO
Pleurogrammus azonus	-35.2524	-wt50m (3)
Arctoscopus japonicus	-17.7438	-PDO
Squalus acanthias	-20.5291	-PDO (1)
Glyptocephalus stelleri	-4.2561	
Hippoglossoides dubius	-11.7849	-PDO (1)
Pleuronectes herzensteini	-0.9105	-PDO
Microstomus achne	-1.6959	NPI (1)
Pandalus eous	-0.4656	-AO (1)

Warm water

Species	Decadal (Warm-Cold)	Interannual
Hippoglossoides pinetorum	-2.2135	
Eopsetta grigorjewi	-0.3874	PDO (1)
Tanakius kitaharai	-0.2805	MOI
Glossanodon semifasciatus	-6.4419	MOI (3)
Paralichthys olivaceus	-0.8323	-NPI (3)
Pagrus major	0.5094	wt50m
Evynnis japonica	1.5133	AO (3)
Dentex tumifrons	0.9436	MOI (1)
Lepidotrigla microptera	-0.0886	MOI (3)
Trichiurus japonicus	-1.0378	

Some warm water species *increase* while most of cold water species *decrease* significantly

Effect from ecological and life history traits

	Interannual			Decadal			Both		
	AIC	b	p value	AIC	b	p value	AIC	b	p value
Affinity	20.287	-0.693	0.596	27.398	-1.253	0.210	28.917	-1.099	0.245
A_m	18.353	1.244	0.331	27.965	0.334	0.361	27.459	0.658	0.152
L_{inf}	20.560	-0.003	0.907	27.668	0.025	0.273	29.796	0.013	0.488

None of the variable can explain the change in abundance!

Why?

- Nonlinearity in response to environmental forcing
  - Biological population can amplify the environmental noise and tend to be highly fluctuated (Hsieh *et al.*, 2005)

- Fishing effect
  - The exploited species can show higher temporal variability (Hsieh *et al.*, 2006)

Conclusion

	Distribution	Abundance
Interannual	Geographical affinity	x
Decadal	x	x
Interannual + Decadal	Asymptotic length	x

- It would be difficult to predict species' response to climate change based on single factor
  - Need to consider the effect of species interaction and biological nonlinear amplification

Acknowledgment

- Stock Assessment and Management Group of Japan Sea National Fisheries Research Institute, FRA

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