Predicting climate change-induced fishery shrink via bottom-up control around the southern waters of Korea using a flow trophic model

Yun Ho **Kang**[1],
Se-Jong Ju[2], Kyoung Soon Shin[2], Young-Gyu Park[2],
Sang-Duk Choi[3], Kyeong-Ho Han[3] and Ho-Seop Yoon[3]

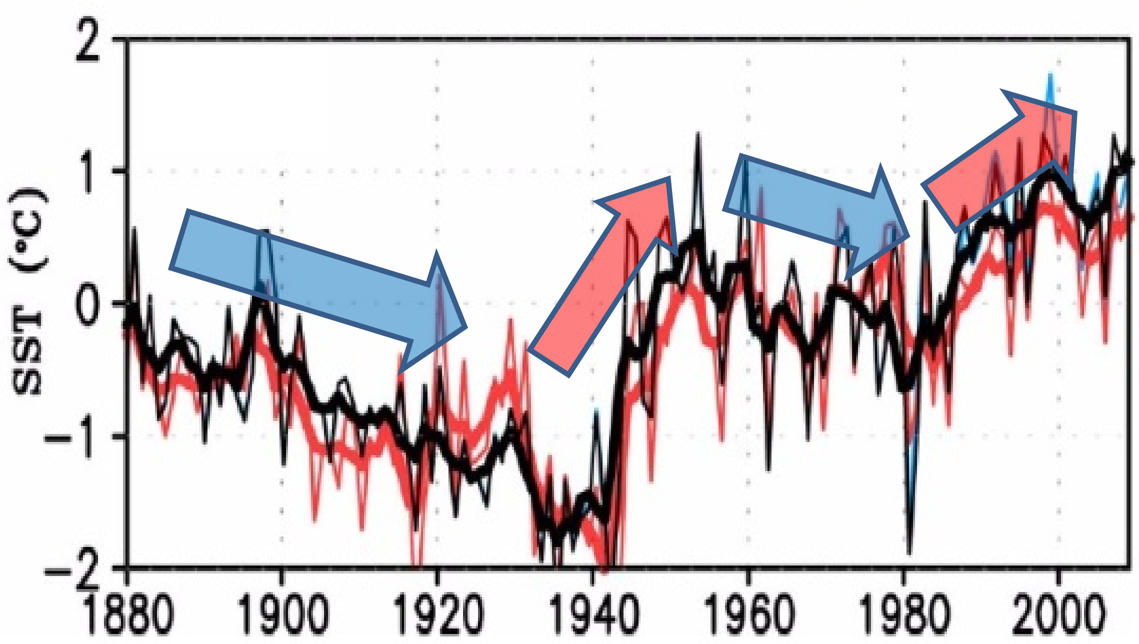
[1]Korea Ocean Search and Salvage Co.

[2]Korea Ocean Research and Development Institute

[3]Division of Marine Technology, Chonnam National University

Contents

Long term SST anomaly



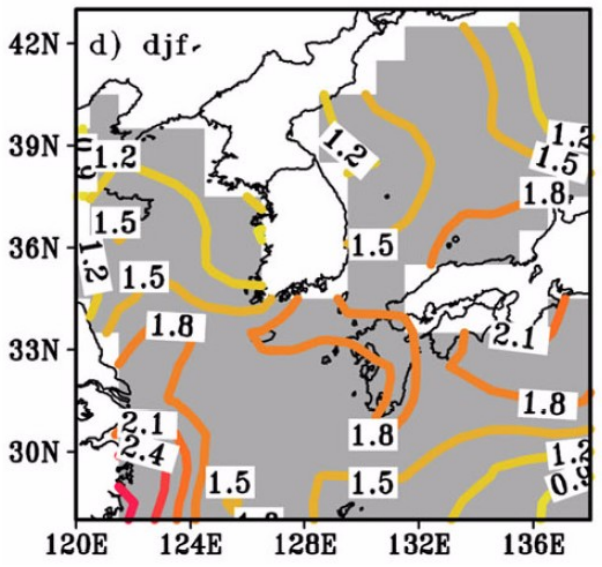
-Time series of the winter mean SST anomaly averaged over the ocean near Korean Peninsular during 1880-2009 (black line-Hadley center surface temperature; blue and red-Goddard institute for space studies SST and Extended Reconstructed SST, respectively; black and red thick lines-5 year running mean for Hadley center SST and ERSST, respectively)

(Source - Kim et al., 2011, Polar and Ocean Research)

Long term SST anomaly

Global mean	Korean Peninsula	South	East	West
0.5	1.0	>1.2 (0.0092 y^{-1})	<1.0	<1.0

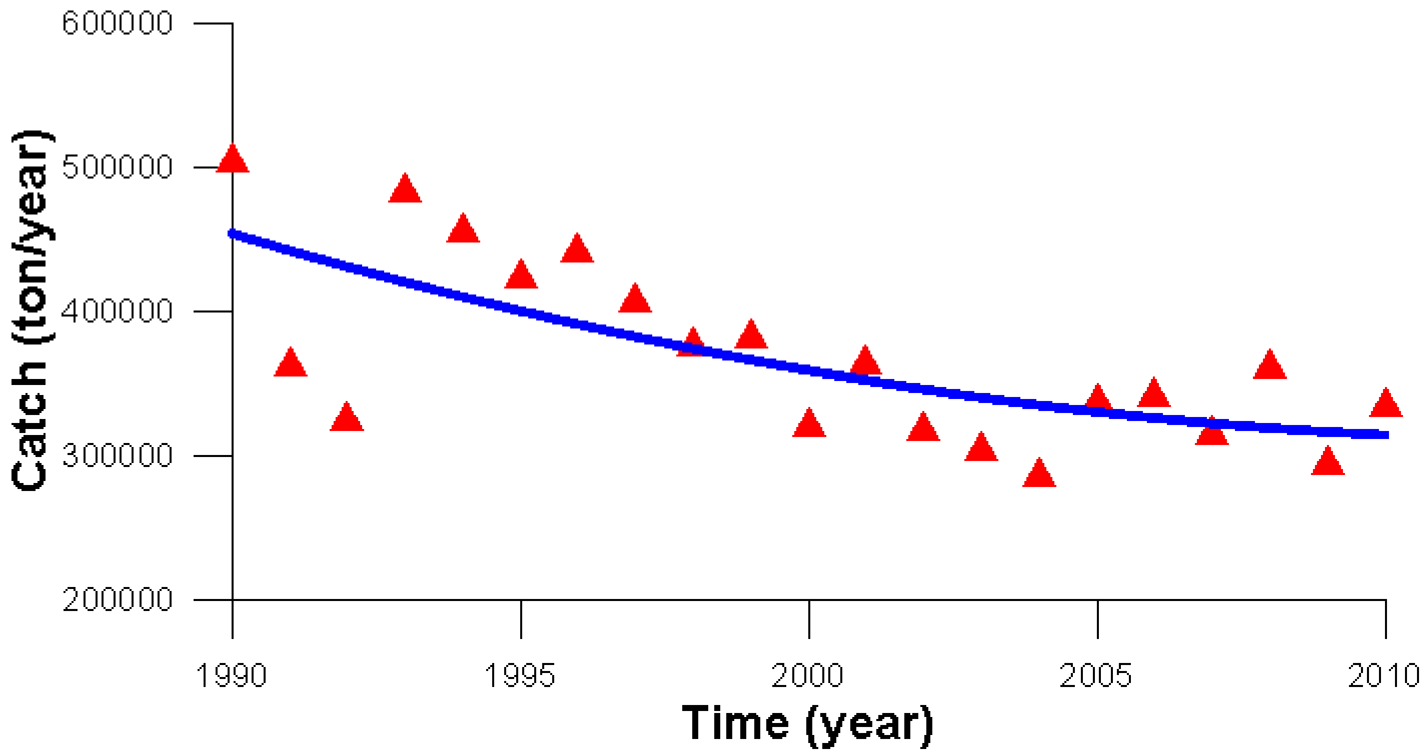
- Comparison of SST anomaly during 1880-2009 over the oceans of global and Korean Peninsular



- Winter mean SST anomaly near Korean Peninsular during 1880-2009

(Source - Kim et al., 2011, Polar and Ocean Research)

Fishery shrinks



−Time series of the fishery catch over the southern waters of Korean during 1990-2010

(source – Statistics Korea)

Study Purpose

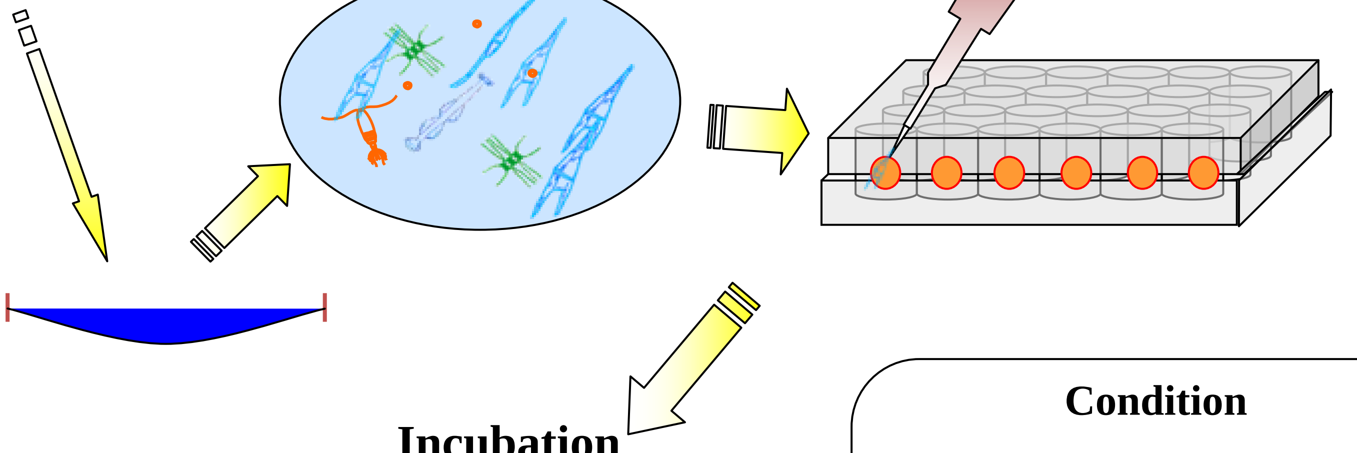
1. Assess the relationship between temperature and phytoplankton growth by laboratory experiments

2. Predict the effects of temperature rise and fishery management in the southern waters of Korea for 100 years using a trophic flow model

Laboratory experiments

- **Isolation and Incubation (Seed)**

Sampling



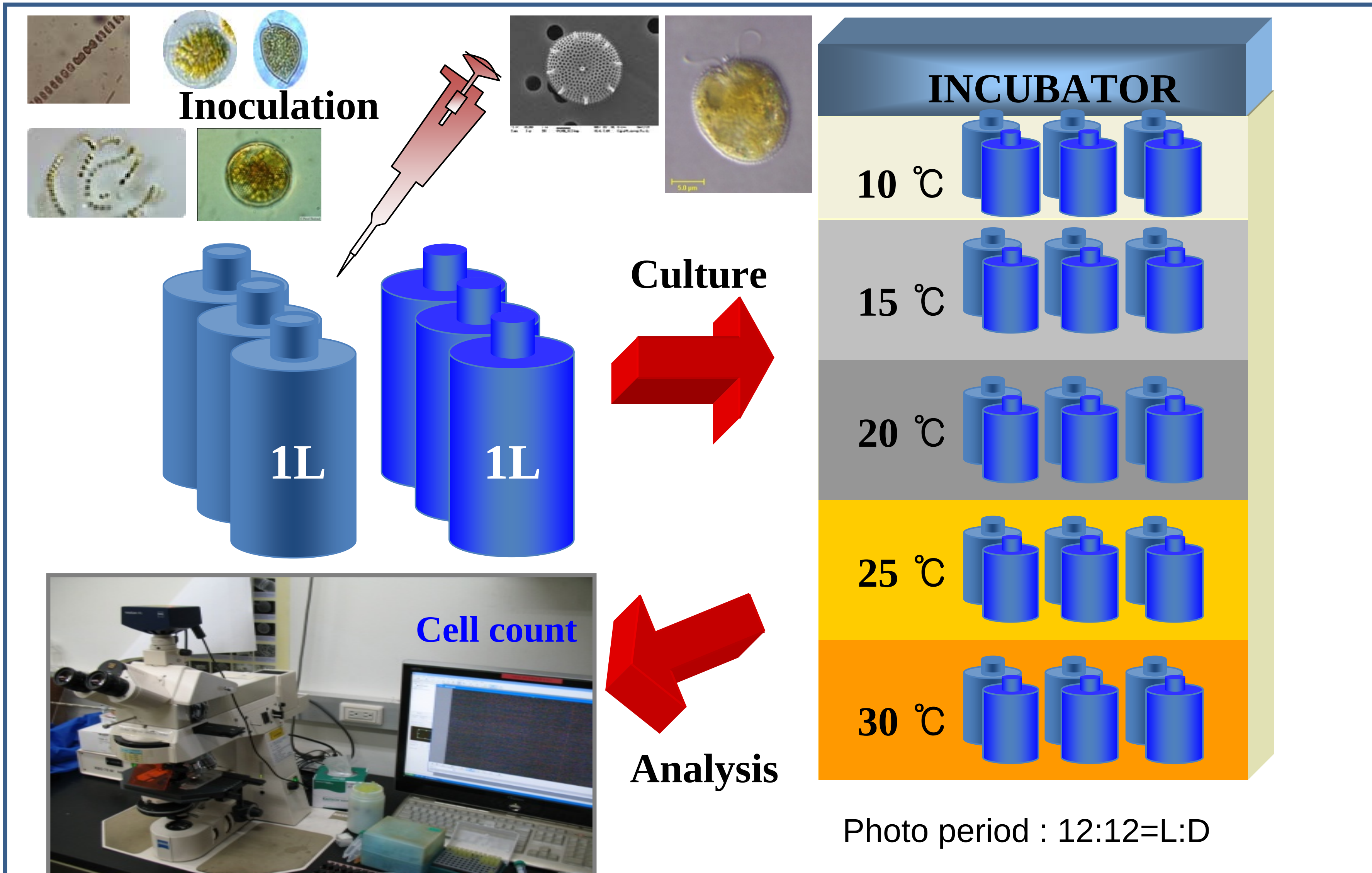
Isolation after
4-5times cleaning

Incubation

Condition

- **Salinity 32psu**
- **Nutrient : F/2 media A, B**
- **Photo period : 12:12=L:D**

Laboratory experiments



Model experiments

- Model Compartments (S/W package)

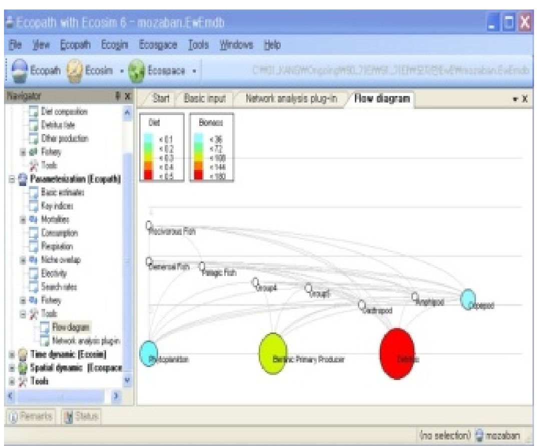
Ecopath (biomass balance, 1992),
Ecosim (time-dynamic, 1997),
Ecospace (spatial simulation, 1999)

-Ecosystem model

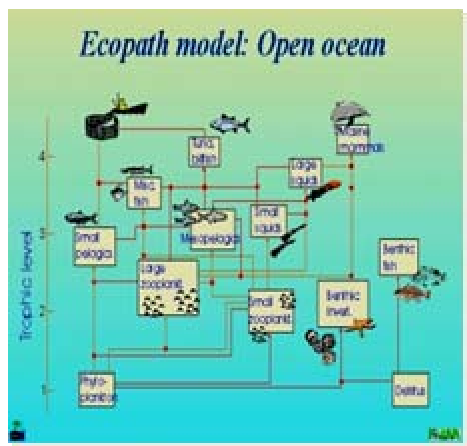
deal with all marine organisms pertaining to a system based on prey-predator relationship,
analyze trophic energy flow and ecological characteristics

- Application

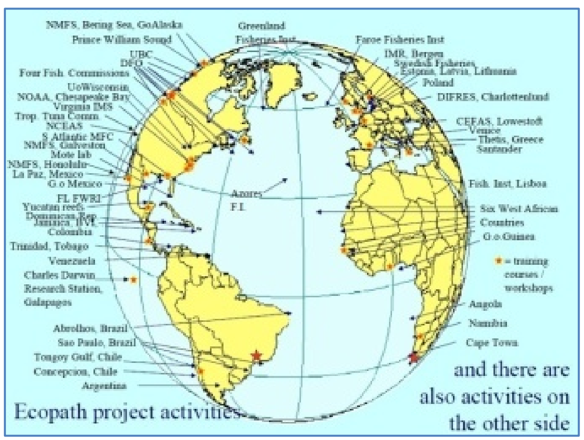
usage- 6,530 registration in 166 countries (2003-2009)



<EwE Software package>



<Trophic flow diagram>



<EwE application site>

Model setup

-Field data

1990~2010 (Statistics Korea)

2007 (KMA, ranching program in Tongyeong)

2007 (KMA, ranching program in Jeonnam)

-Categorizing organisms

based on TL, DC, HA etc.

total 37 : detritus-1,
primary producer-2,
invertebrate–9,
fish–25

-Basic parameters

Habitat area,
Biomass (B=C/F, F=0.1~0.3),
Production/Biomass,
Consumption/Biomass,
Ecotrophic Efficiency

열1	Group name	B(t/km²)	P/B(/year)	Q/B(/year)
1	Sharks	0.013	0.590	5.200
2	Goosefish	0.314	1.260	3.160
3	Hairtail	1.142	1.590	5.158
4	Cephalopoda	1.600	2.500	7.500
5	Spanish mackerel	0.963	2.190	6.642
6	Anguilliformes	0.923	0.490	2.449
7	Whales	0.010	0.280	8.331
8	Rockfish	0.250	0.388	1.701
9	Large pelagics	0.201	0.659	2.806
10	Silver pomfret	0.422	1.280	6.400
11	Demersal fish	1.500	2.200	6.000
12	Grey mullet	0.359	0.433	2.616
13	Benthic fish	0.900	2.700	10.000
14	Croaker	1.458	1.600	3.400
15	Flatfish	1.400	1.700	5.400
16	Pacific sardine	0.100	1.800	8.796
17	Pacific herring	0.499	0.900	7.960
18	Shad	0.425	0.700	6.400
19	Small pelagics	2.700	2.700	8.000
20	Jellyfish	0.800	5.000	25.000
21	Filefish	0.200	1.184	3.650
22	Sparidae	0.500	1.200	6.000
23	Mackerel	1.302	2.790	5.881
24	Horse mackerel	0.444	2.150	9.847
25	Anchovy	12.622	3.500	17.341
26	Crabs	1.400	3.000	9.000
27	Shrimps	2.700	3.320	7.690
28	Benthic crustacean	2.500	3.300	16.000
29	Echinodermata	1.600	1.500	3.100
30	Bivalvia	1.500	2.200	12.000
31	Molluscs	3.700	3.000	7.000
32	Gastropoda	1.500	1.500	6.000
33	Polychaetes	2.500	3.800	13.500
34	Zooplankton	8.000	30.000	190.000
35	Phytoplankton	11.000	120.000	
36	Benthic producer	10.000	12.000	
37	Detritus	150.000		

Model setup

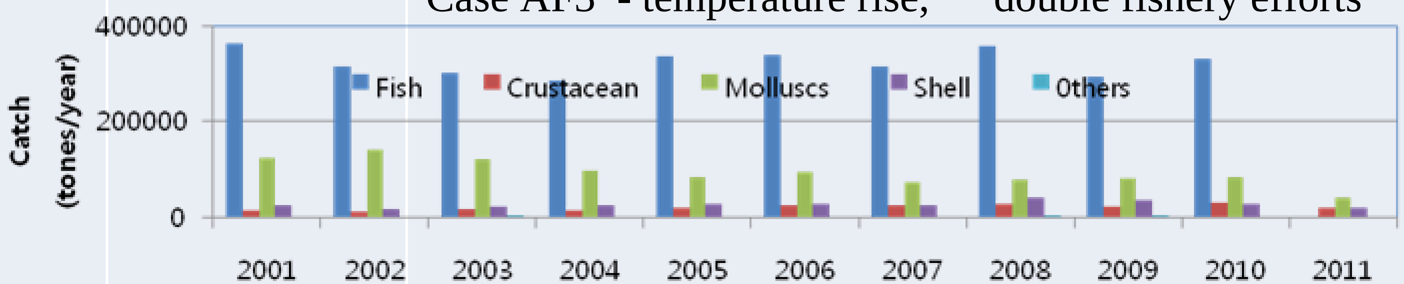
−Diet composition : stomach contents

Prey ₩ predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1 Sharks	0.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Goosefish	0	0.006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 Hairtail	0.023	0.164	0.01	0	0.01	0	0.02	0	0.007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 Cephalopoda	0.1	0.015	0.07	0.16	0.01	0	0.02	0.005	0.037	0.07	0.05	0	0.04	0.01	0	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0
5 Spanish mackerel	0.05	0.005	0	0	0	0	0.03	0	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 Anguilliformes	0.002	0.029	0	0	0	0	0.02	0	0	0	0	0	0.009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Whales	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 Rockfish	0	0	0	0	0	0	0.001	0.001	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9 Large pelagics	0	0.017	0	0	0	0	0.015	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 Silver pomfret	0	0.028	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 Demersal fish	0.013	0.077	0.1	0	0.02	0.2	0.02	0	0	0	0.055	0	0.06	0.1	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 Grey mullet	0.139	0	0	0	0	0	0.014	0.029	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 Benthic fish	0	0.05	0.05	0	0.02	0.1	0.01	0.05	0.028	0.075	0.05	0.2	0	0	0.05	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0
14 Croaker	0	0.42	0.07	0	0.06	0	0.02	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 Flatfish	0	0	0	0	0.04	0.1	0.02	0.005	0	0	0.085	0	0.003	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 Pacific sardine	0	0	0.02	0	0.001	0	0.02	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 Pacific herring	0	0	0.02	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 Shad	0	0	0.02	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 Small pelagics	0.04	0.075	0.25	0.26	0.1	0	0.02	0.4	0.005	0.03	0	0.21	0	0.02	0.06	0	0	0	0	0.019	0	0	0.004	0	0	0	0	0	0	0	0	0	0	0
20 Jellyfish	0.07	0	0	0	0.25	0	0.02	0	0.059	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21 Filefish	0.05	0	0.02	0	0	0	0.02	0	0.008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22 Sparidae	0.038	0	0	0	0.03	0	0.03	0	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23 Mackerel	0.07	0.036	0	0	0.094	0	0.02	0	0.051	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24 Horse mackerel	0.141	0.015	0.05	0	0.02	0	0.02	0	0.165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 Anchovy	0.154	0.04	0.04	0.26	0.05	0	0.01	0	0.319	0	0	0	0	0.06	0	0	0	0	0	0	0	0.024	0.016	0.004	0	0	0	0	0	0	0	0	0	0
26 Crabs	0.06	0.002	0.02	0.09	0	0.1	0.13	0.06	0.04	0.03	0.1	0	0.066	0.05	0.01	0	0	0	0.005	0	0	0.053	0.008	0.002	0	0	0	0	0	0	0	0	0	0
27 Shrimps	0.03	0.021	0.05	0.09	0.135	0.1	0.13	0.07	0.142	0.01	0.1	0	0.287	0.27	0.02	0	0	0	0.005	0	0	0.06	0.002	0.001	0	0.07	0	0	0	0	0	0	0	0
28 Benthic crust.	0.01	0	0.02	0.04	0.12	0.2	0.02	0.14	0.064	0.002	0.3	0.02	0.095	0.05	0.2	0	0	0	0.03	0	0	0	0	0.003	0	0	0	0	0.01	0	0	0	0	0
29 Echinodermata	0	0	0.02	0	0	0.005	0.01	0	0	0.003	0.05	0.07	0.044	0	0.05	0.002	0	0	0	0	0.077	0.15	0	0	0	0	0	0	0.06	0	0	0	0	0
30 Bivalvia	0	0	0	0.09	0	0.005	0	0	0	0	0	0.07	0.1	0.05	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0	0	0	0	0
31 Molluscs	0	0	0.02	0	0	0	0	0	0	0.03	0	0	0	0	0.12	0	0	0	0	0	0	0	0	0	0	0.3	0.12	0.08	0.06	0	0	0	0	0
32 Gastropoda	0	0	0	0	0	0.045	0	0	0	0	0.06	0.07	0.05	0.05	0	0.001	0	0	0	0	0.077	0.05	0	0	0	0	0	0	0	0	0	0	0	0
33 Polychaetes	0.003	0	0.05	0	0	0.005	0	0	0.072	0.02	0.01	0.07	0.196	0.2	0.05	0	0	0	0.02	0	0	0.07	0	0	0	0	0	0.05	0.02	0	0	0	0	0
34 Zooplankton	0	0	0.1	0	0.04	0.14	0.3	0.24	0	0.42	0.07	0.14	0	0.14	0.01	0.997	1	1	0.9	0.9	0.769	0.2	0.49	0.49	0.52	0	0.2	0.05	0.005	0.1	0.05	0	0	0
35 Phytoplankton	0	0	0	0	0	0	0	0	0	0.01	0.05	0	0	0	0	0	0	0	0	0	0.077	0.173	0.46	0.49	0.48	0	0.03	0.07	0.005	0.05	0.08	0.3	0	0.7
36 Benthic producer	0	0	0	0.01	0	0	0	0	0	0	0.02	0.07	0.01	0	0.1	0	0	0	0	0.08	0	0.1	0	0	0	0.2	0.12	0.15	0.55	0.15	0.17	0.65	0	0
37 Detritus	0	0	0	0	0	0	0	0	0	0	0	0.07	0	0	0.19	0	0	0	0.04	0	0	0.05	0	0	0	0.43	0.53	0.6	0.29	0.7	0.7	0.05	1	0.3
38 Import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39 Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Model experiments

-Perform model experiments after model setup

Model	Simulation time	Experiment contents
ECOPATH	1 yr	**Model calibration** analysis - Trophic flow structure, Mixed Trophic Impact Prepare - basic data for ECOSIM
ECOSIM	100 yr	**Predict and compare the effects of climate change and fishery managements** Case 0 - no climate change, equal fishery efforts Case AF1 - temperature rise, half fishery efforts Case AF2 - temperature rise, equal fishery efforts Case AF3 - temperature rise, double fishery efforts



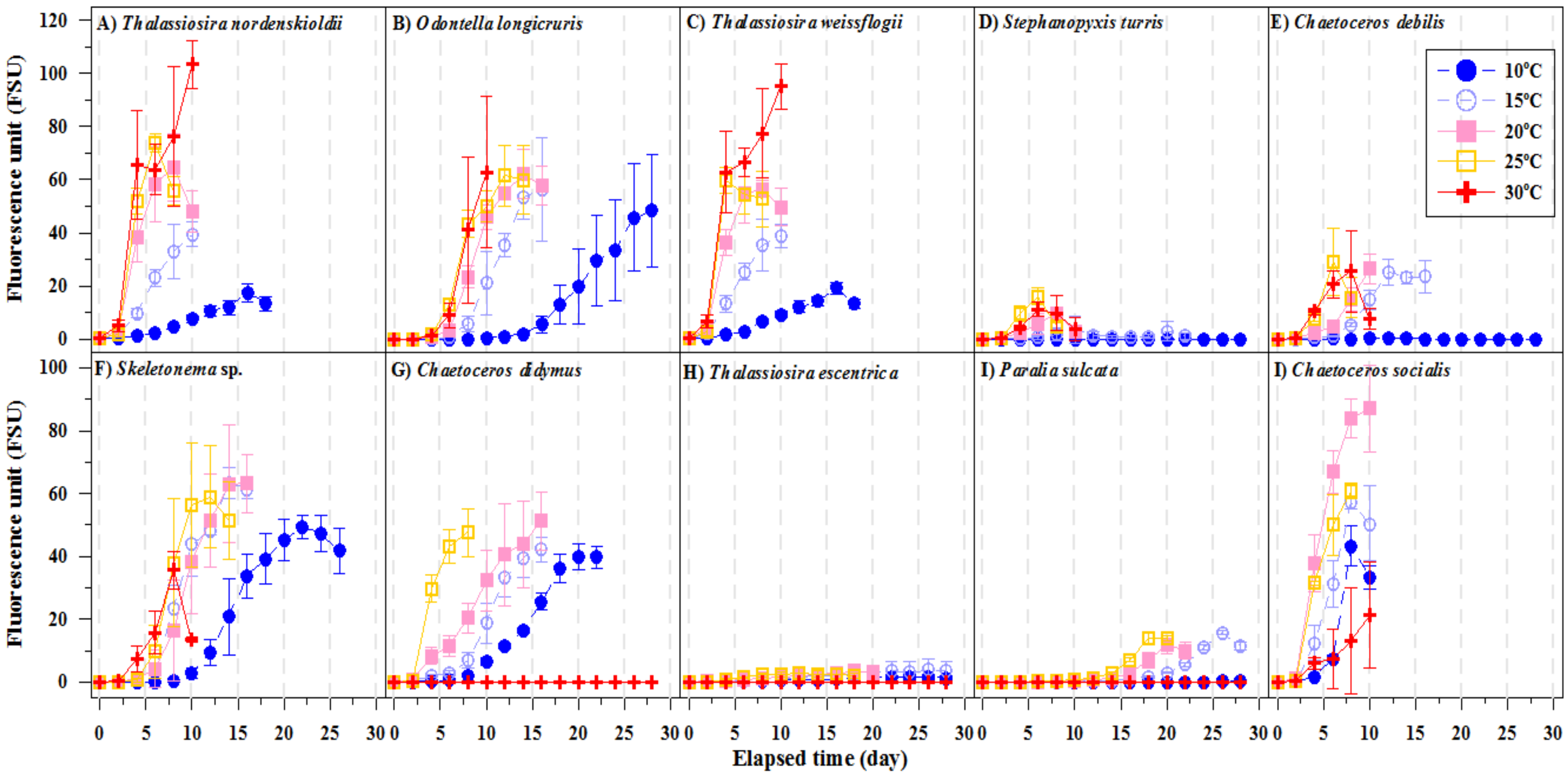
(fishery efforts – mean of 10 years' catch history from 2001 to 2010)

Model experiments

– How to deal with the effect of temperature rise in the model ?

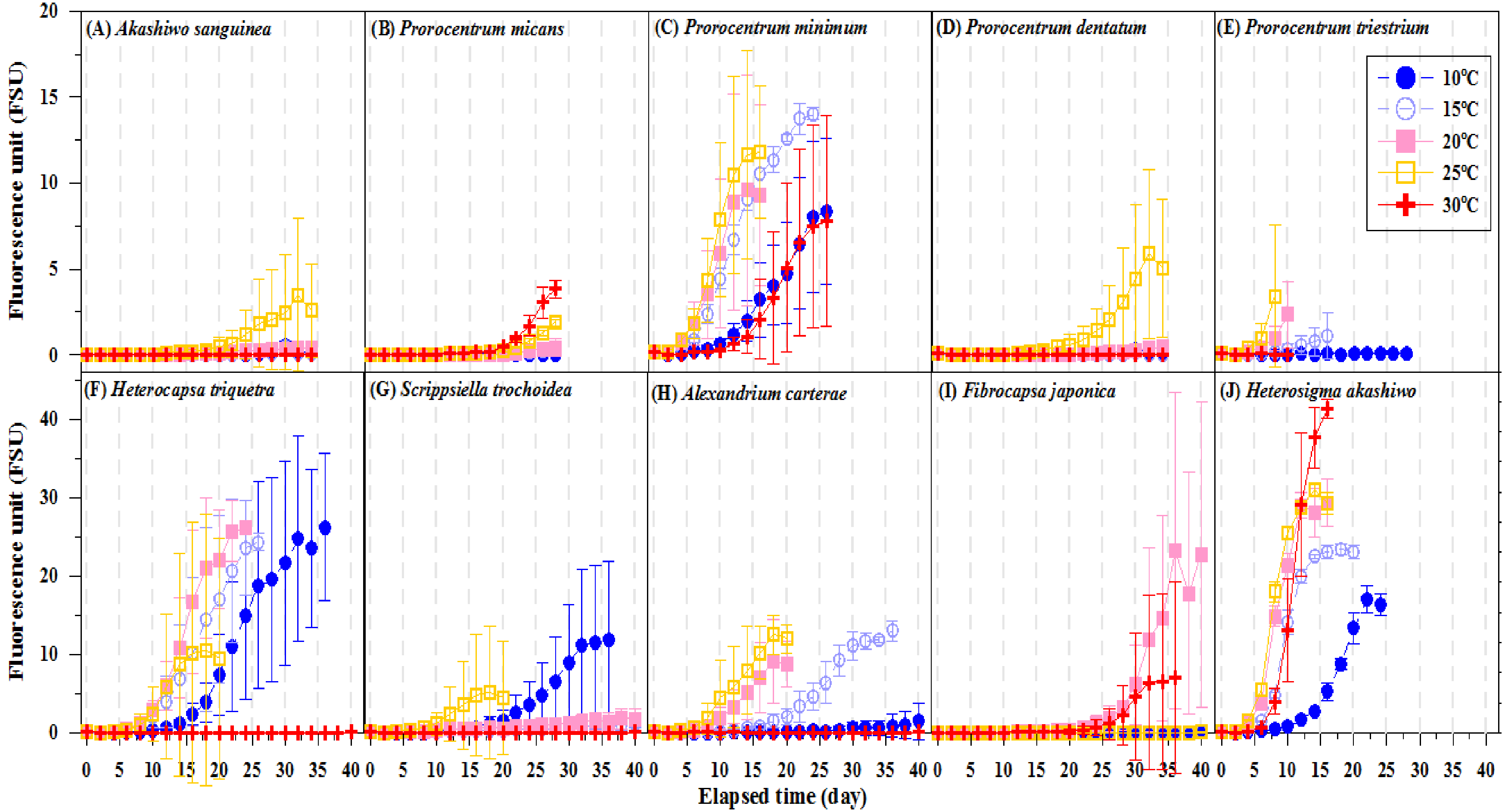
Source	**Contents**	**Parameters in EwE** **Phytoplankton biomass (forcing function)**
Long term history	0.92 ℃ rise for 100 years by linear extrapolation	**- 6.1 %** reduction based on Temp. vs. phytoplankton growth relationship
Model prediction (GFDL CM2.1 + TOPAZ)	Temp. : 2.346 ℃ (17.825~20.171) (mean of 2001-2020 to that of 2081-2100)	**-15.6 %** reduction based on Temp. vs. phytoplankton growth relationship
	Chl. : 0.030 mg/m^3 (0.296~0.266) (mean of 2001-2020 to that of 2081-2100)	**-10.1 %** reduction

Laboratory experiments



- Temperature vs. growth relationship of diatom

Laboratory experiments



- Temperature vs. growth relationship of dinoflagellates and raphido (heterosigma and akashiwo)

Ecopath calibration

Parameter	General range	Model results
EE	< 1.0 (0.0~0.95)	0.00 ~ 0.99
GE	> 0.3	0.03 ~ 0.48
NE	0 < NE < 1.0 > GE	0.04 ~ 0.61

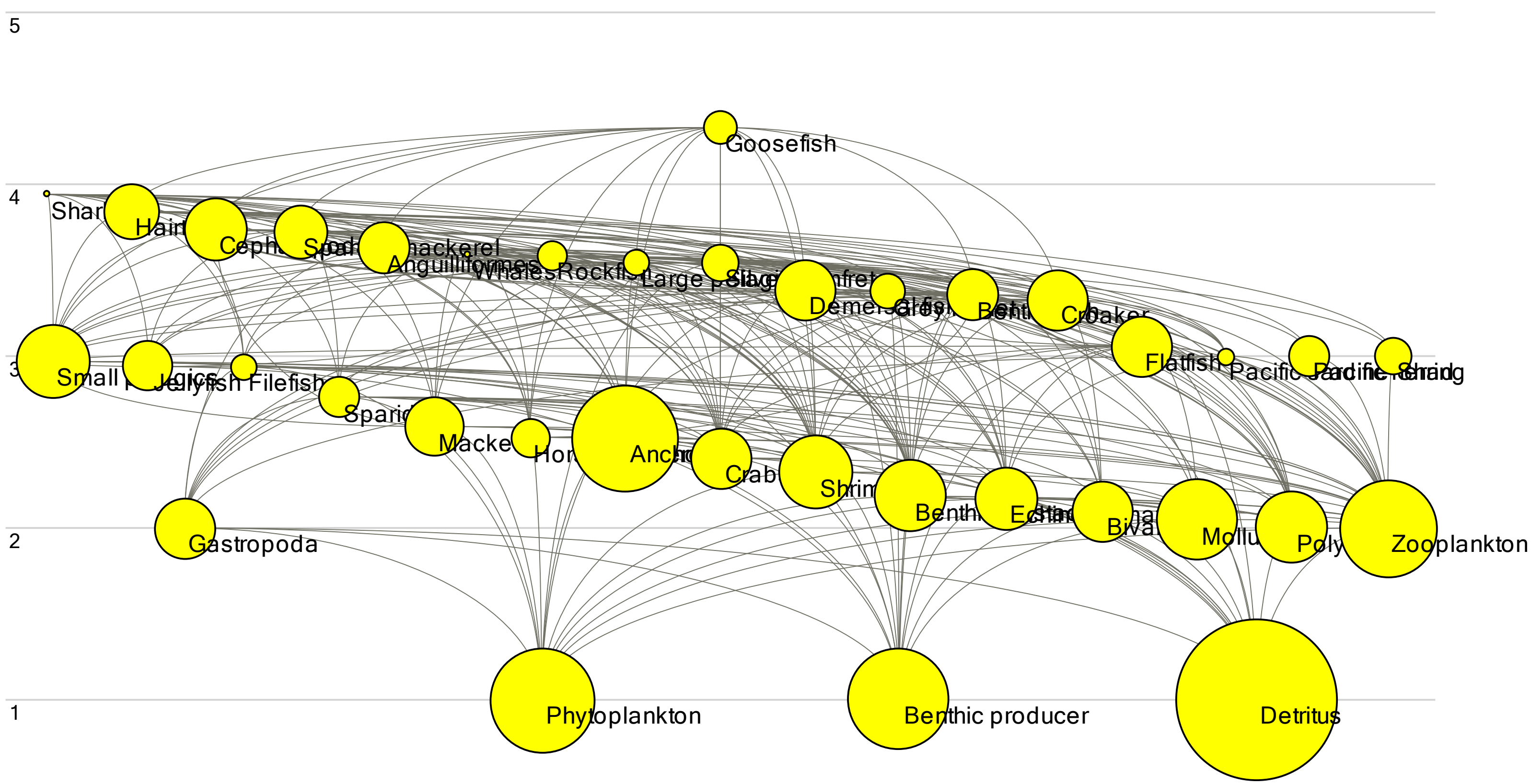
-EE: Ecotrophic Efficiency, fraction of the production that is used in the system, i.e. either passed up the food web, used for biomass accumulation, migration or export

-GE: Gross food conversion Efficiency, (P/Q)

-NE: Net Efficiency

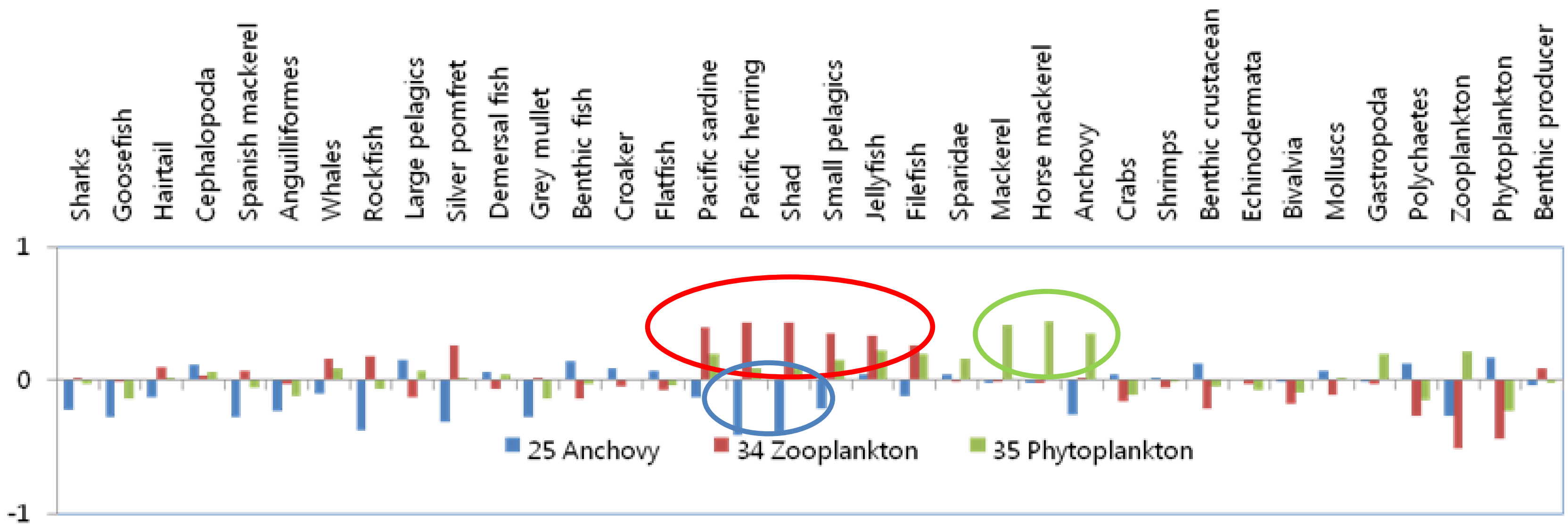
	Group name	E.E.	G.E.	N.E.
1	Sharks	0.714	0.113	0.142
2	Goosefish	0.293	0.399	0.498
3	Hairtail	0.382	0.308	0.385
4	Cephalopoda	0.948	0.333	0.417
5	Spanish mackerel	0.165	0.330	0.412
6	Anguilliformes	0.961	0.200	0.250
7	Whales	0.000	0.034	0.042
8	Rockfish	0.762	0.228	0.285
9	Large pelagics	0.560	0.235	0.294
10	Silver pomfret	0.329	0.200	0.250
11	Demersal fish	0.976	0.367	0.458
12	Grey mullet	0.958	0.166	0.207
13	Benthic fish	0.851	0.270	0.338
14	Croaker	0.816	0.471	0.588
15	Flatfish	0.910	0.315	0.394
16	Pacific sardine	0.702	0.205	0.256
17	Pacific herring	0.656	0.113	0.141
18	Shad	0.902	0.109	0.137
19	Small pelagics	0.946	0.338	0.422
20	Jellyfish	0.612	0.200	0.250
21	Filefish	0.605	0.324	0.405
22	Sparidae	0.712	0.200	0.250
23	Mackerel	0.311	0.474	0.593
24	Horse mackerel	0.730	0.218	0.273
25	Anchovy	0.200	0.202	0.252
26	Crabs	0.914	0.333	0.417
27	Shrimps	0.994	0.432	0.540
28	Benthic crustacean	0.966	0.206	0.258
29	Echinodermata	0.931	0.484	0.605
30	Bivalvia	0.816	0.183	0.229
31	Molluscs	0.981	0.429	0.536
32	Gastropoda	0.722	0.250	0.313
33	Polychaetes	0.677	0.281	0.352
34	Zooplankton	0.746	0.158	0.197
35	Phytoplankton	0.898	-	-
36	Benthic producer	0.249	-	-
37	Detritus	0.760	-	-

Ecopath simulation



– A trophic flow diagram of the ecosystem. Box size is proportional to the compartmental biomass in terms of wet weight per unit area.

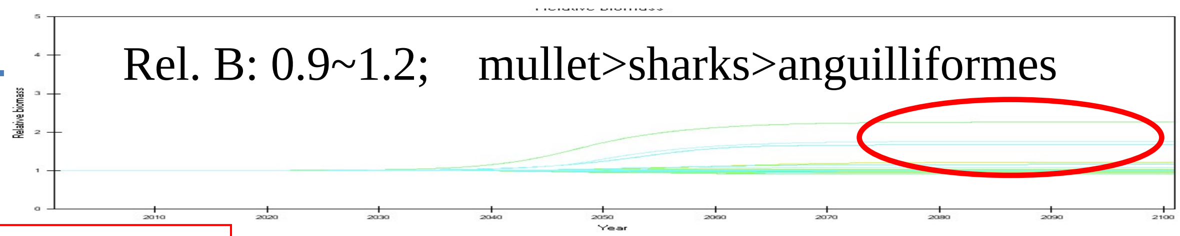
Ecopath simulation



-Mixed trophic impacts showing the assessment of the direct and indirect interactions between groups based on prey-predator relationship.

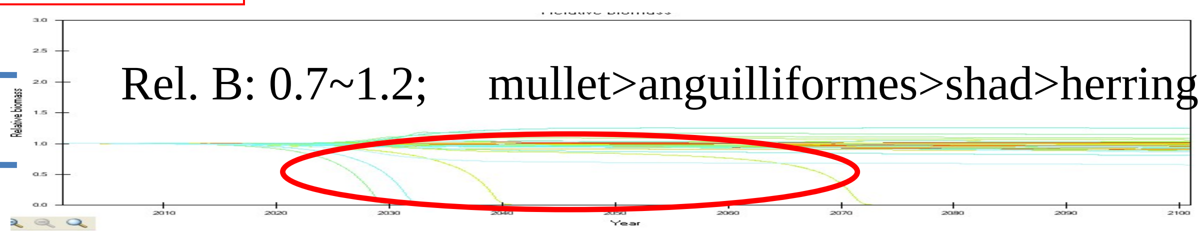
-Phytoplankton : (+) impacts on mackerel, anchovy
-Zooplankton : (+) impacts on herring, sardine, shad
-Anchovy : (-) impacts on herring, shad, rockfish

Ecosim simulation

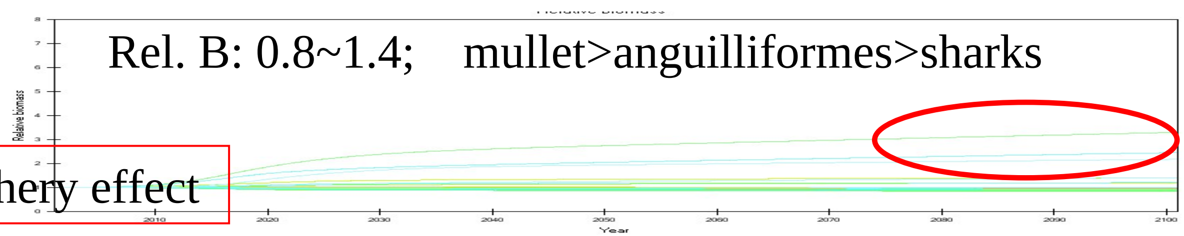


Case 0
(no T. rise, equal F)

Temp. effect

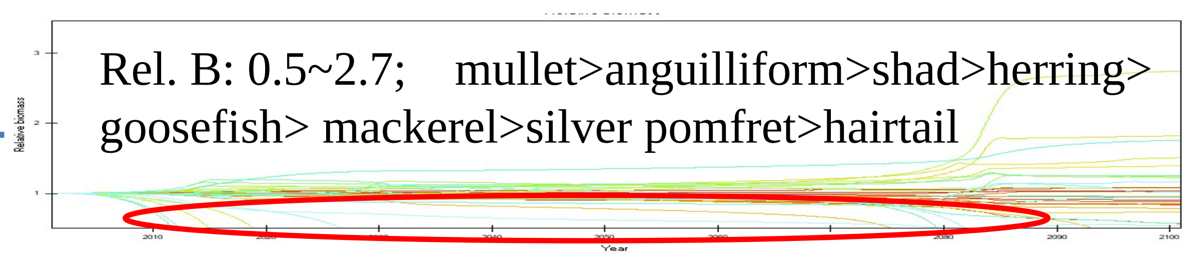


Case AF2
(T. rise, equal F)



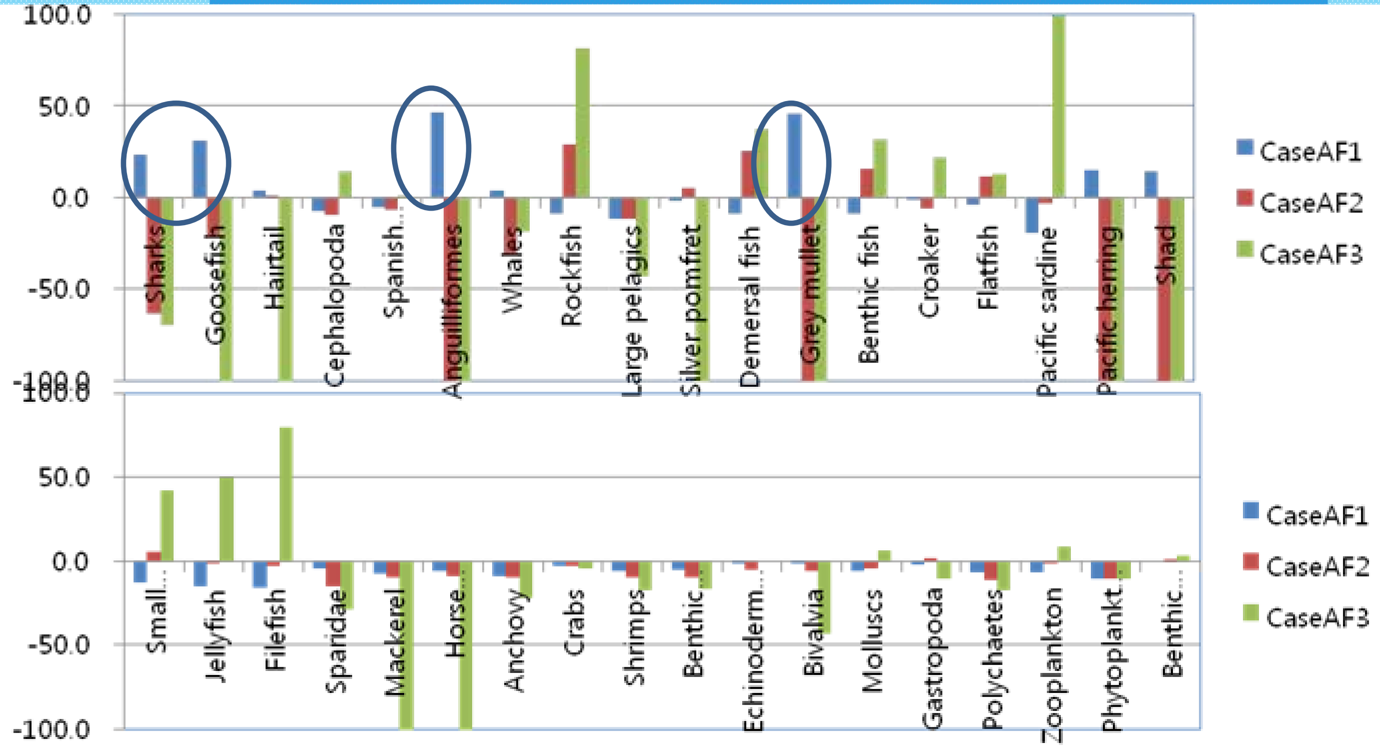
Case AF1
(T. rise, half F)

Fishery effect



Case AF3
(T. rise, double F)

Ecosim simulation



-Biomass reduction(%, compared to Case 0) by impacts of temperature and fishery managements for 100 years

-Case AF1 : (+) anguilliformes, grey mullet, goosefish, sharks

-Case AF2 : (+) rockfish, demersal fish; (-) anguilliformes, mullet, herring, shad

-Case AF3 : (+) sardine, rock fish, filefish, jellyfish, small pelagics
(-) sharks, goosefish, hairtail, anguiliformes, pomfret, mullet, herring, shad, mackerel

ECOSIM simulation

-Temperature effects (Case 0 vs. Case AF2)

	Case 0	Case AF2
Total except detritus	78.3	71.7 (-8.4%)
Fish	31.8	27.5 (-13.7%)
Invertebrates	17.5	16.4 (-6.4)

-Biomass shrink (t/km²)

fish 13.7%,
invertebrates 6.4%,
total except detritus 8.4%

-Fishery management effects (Case AF2 vs. Case AF1)

	Case AF2 (equal F)	Case AF1 (half F)
Total except detritus	71.7	75.3 (4.9%)
fish	27.5	31.1 (13.2%)
invertebrates	16.4	16.7 (2.3%)

-Biomass increase (t/km²)

fish 13.2 %,
invertebrates 2.3%,
total except detritus 4.9%

ECOSIM simulation

-Fishery management effects (Case AF2 vs. AF3)

	Case AF2 (equal F)	Case AF3 (double F)
Total except detritus	71.7	69.9 (-2.6%)
fish	27.5	25.4 (-7.4%)
invertebrates	16.4	15.5 (-4.9%)

-Biomass shrink (t/km²)

fish 7.4%,
invertebrates 4.9%,
total except detritus 2.6%

sharks, goosefish, hairtail, anguilliformes, pomfret, mullet, herring, shad, mackerel

Discussion

1. Basic parameters for EwE model

   Biomass(B=C/F), PB, QB, DC

   lack field measurements or laboratory experiments

   possibly under- or over-estimated , while calibrated

   need to refine raw data and correct basic parameters

2. Temperature vs. growth relationship

   conduct laboratory experiments for various major phytoplankton species

   find the relationship in a quantitative manner

   but further works for calibration and verification in application

   (i.e. pilot test in a lower trophic food web)

Conclusion

1. Temperature impacts

biomass shrinks 14, 6, 8% for fish, invertebrates and total except detritus

2. Fishery management impacts

– Half efforts
biomass increase 13, 2, 5% for fish, invertebrates and total groups except detritus.

- Double efforts
biomass decrease 7, 5, 3% for fish, invertebrates and total groups except detritus.

3. The establish model can be a useful tool for ecosystem and fishery management.

THANK YOU