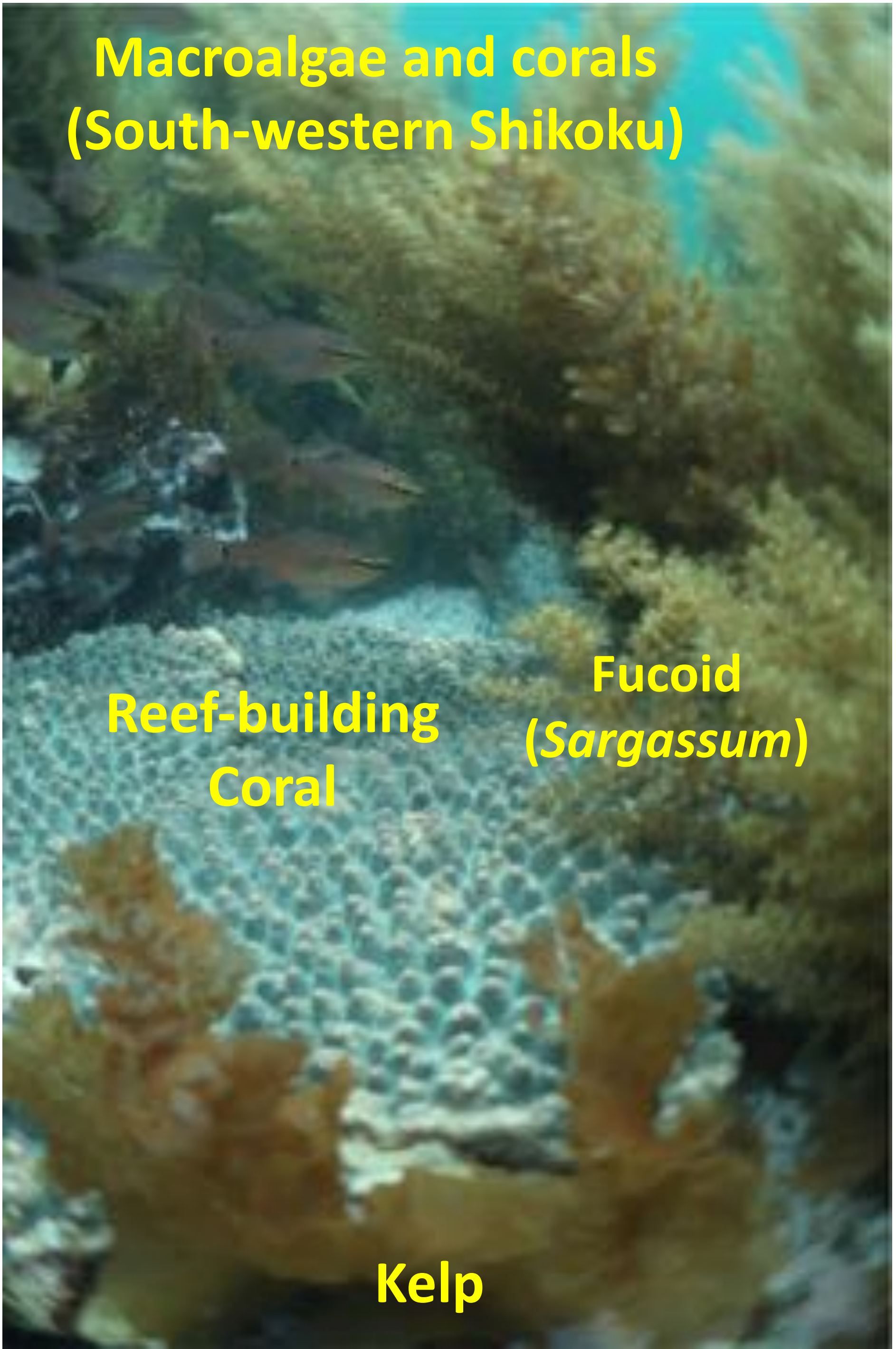

October 22 2019
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S5 Trends in ocean and coastal ecosystems and their services and its future

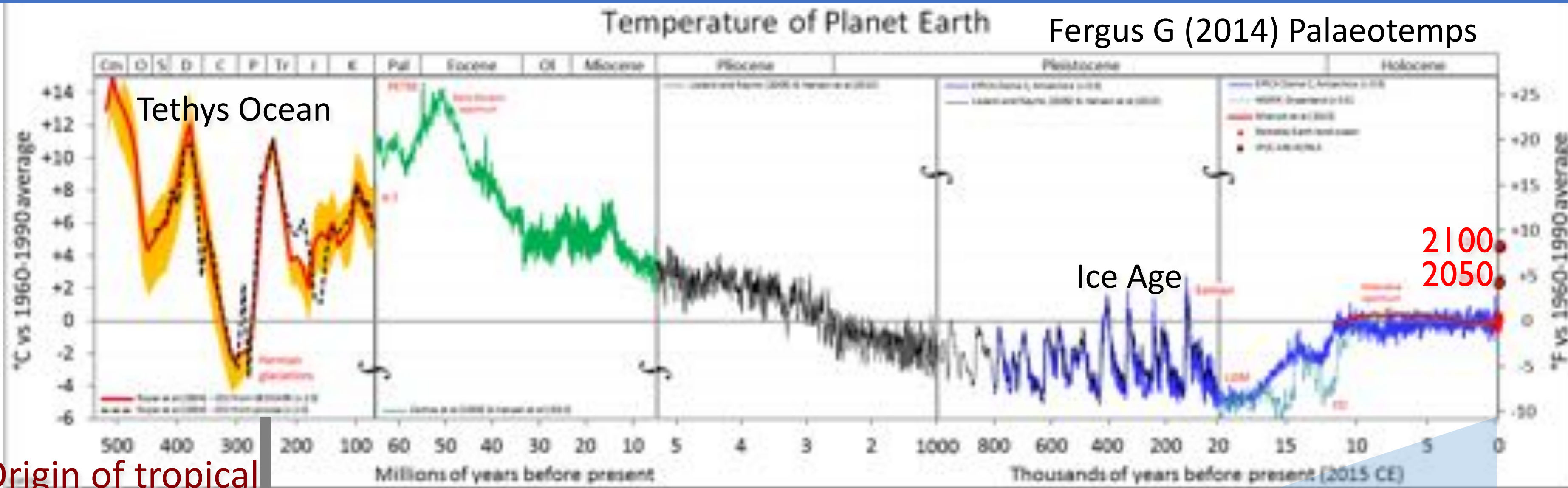
Community shifts from macroalgae to corals under climate warming: Underlying processes and adaptation strategies

Naoki H. Kumagai,
Jorge García Molinos, Hiroya Yamano, Shintaro Takao, Masahiko Fujii, Yasuhiro Yamanaka

From Fig.1 in Kumagai *et al.* (2018) PNAS

Global climate changes and response of organisms

Fergus G (2014) Palaeotemps

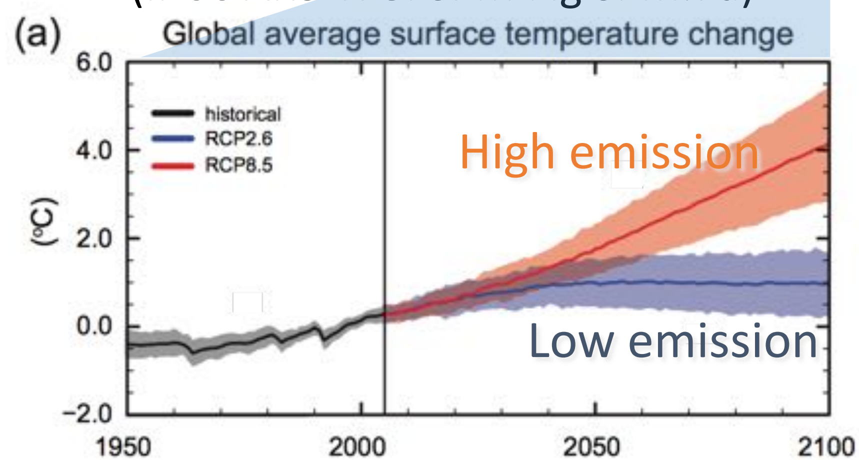


Origin of tropical marine organisms

Reef-building corals appeared c.a. 250 millions years ago (much hotter than present)

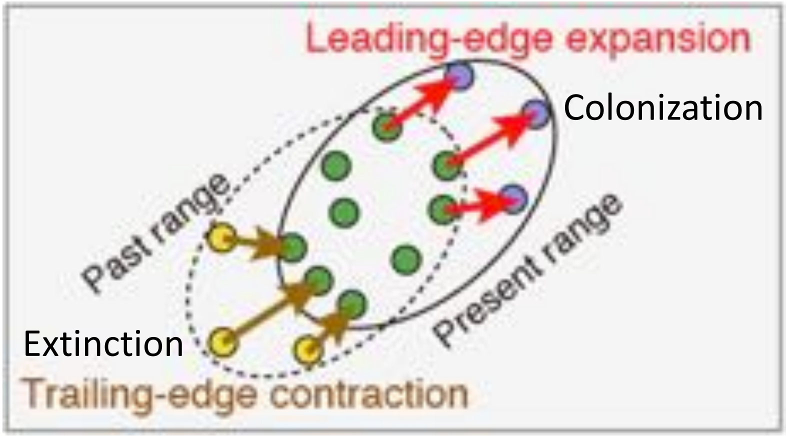
Not temperature itself but the rate of warming is the matter

(IPCC AR5 WGI SPM Fig SPM.7a)

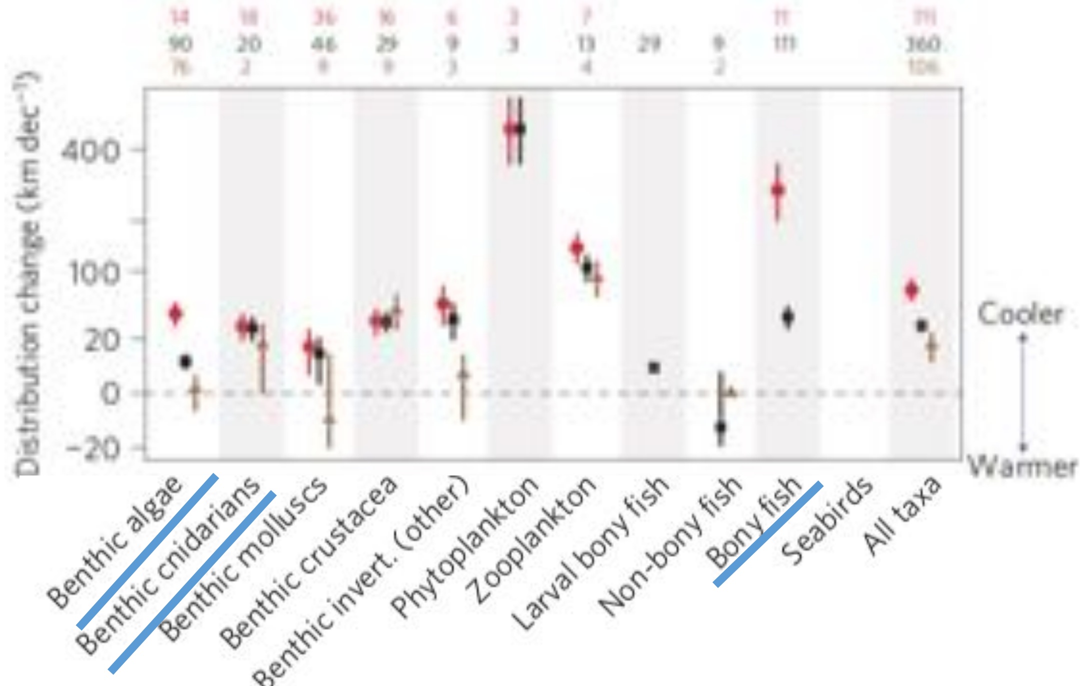


Anthropocene:
Faster warming than ever

Distribution range of marine taxa is changing under climate changes

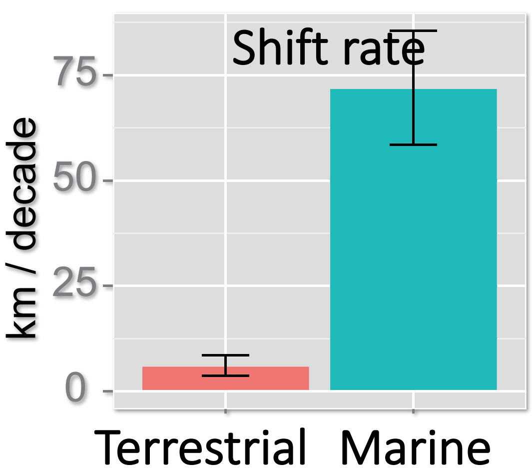


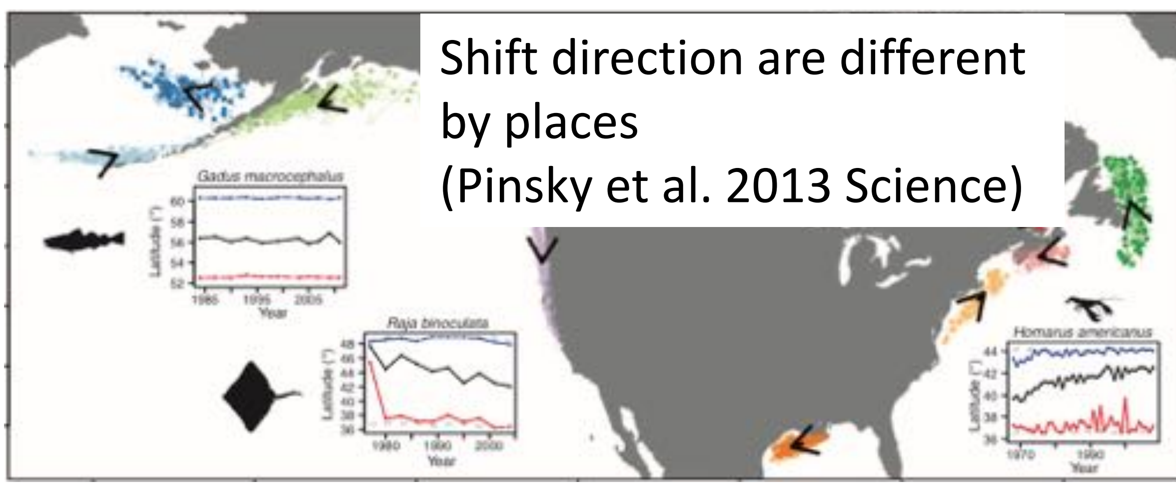
Range is expected to shift toward cooler zone through colonizations and local extinctions



Shift rates are different among taxa

(Poloczansca et al. 2013 Nature CC)

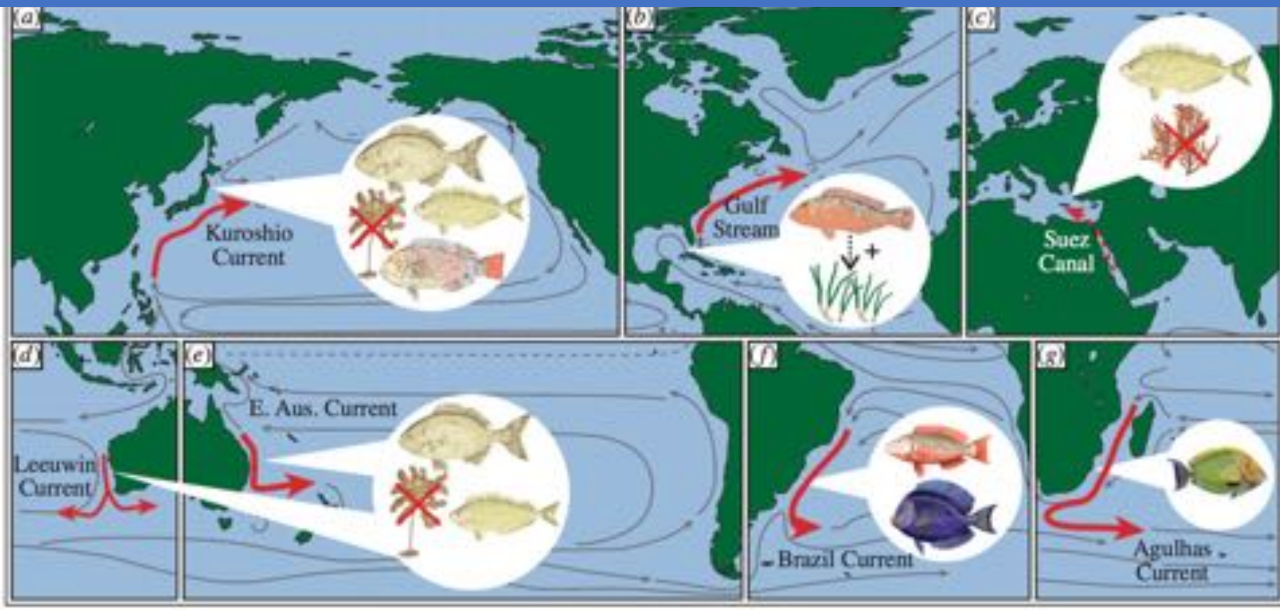




Shift direction are different by places

(Pinsky et al. 2013 Science)

What will happen if interacted taxa shifts at different rate?



Tropical herbivorous fishes are expanding into temperate zone –> overgrazing: "Tropicalization" brought by boundary currents (Vergés et al. 2014 Proc R Soc B)

Macroalgae

Shift slower, decrease

New interaction

Herbivorous fishes

Shift faster newly colonize

Invertebrate herbivores

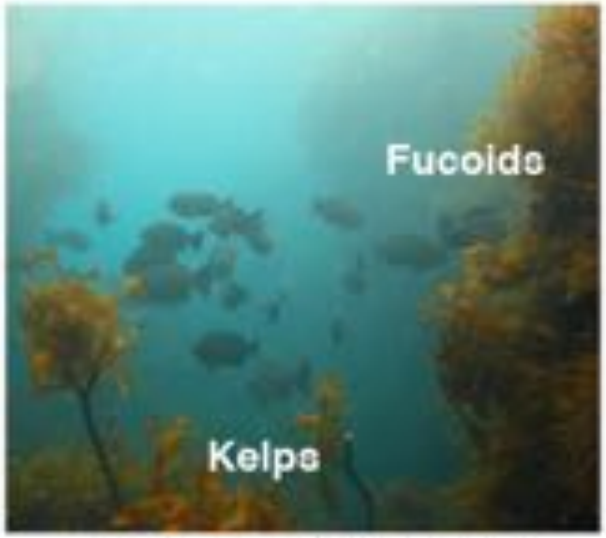
Less herbivorous impacts

Vertebrate herbivores

Intense herbivorous impacts

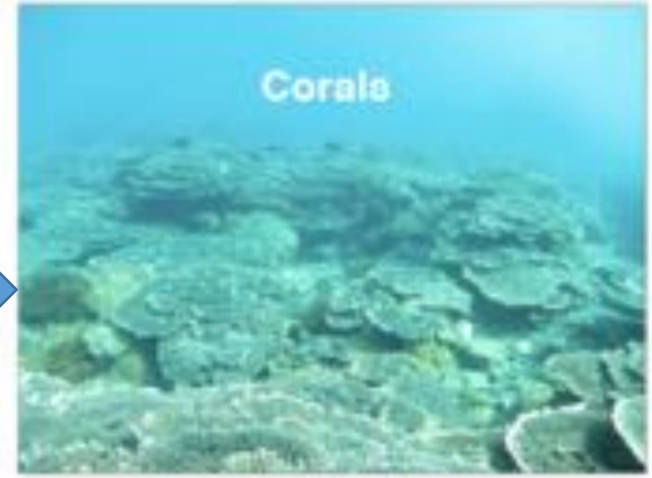
Coral expansion into temperate macroalgal communities

Corals: spatial competition with macroalgae



Kelp – fucoid dominant

Community shift from macroalgae-to-corals dominance



Coral dominant

Macroalgae: decrease

New interaction

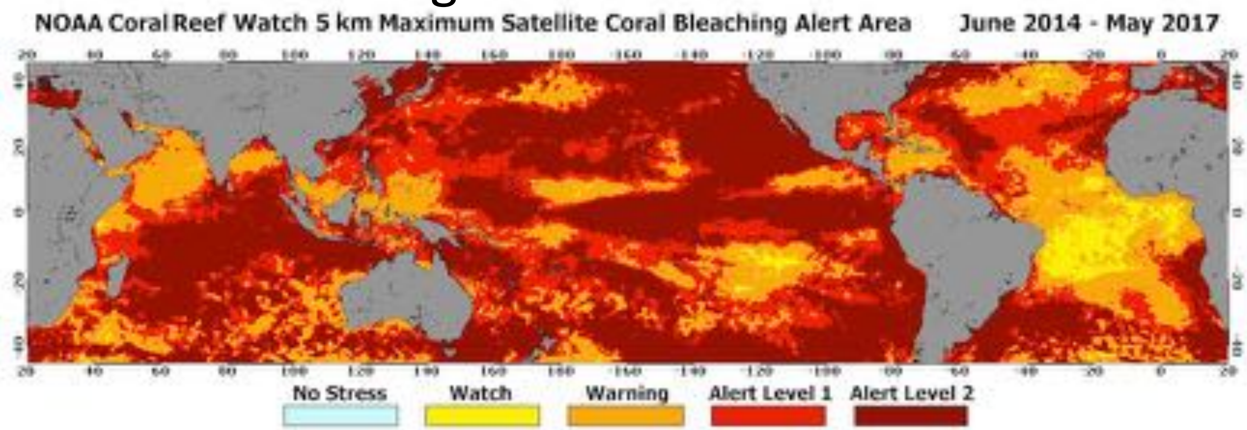
Increase

Corals, herbivorous fishes: shift faster

Distribution range shifts in interacted habitat forming taxon –> ecosystem-wide implications (biodiversity, ecosystem function, ocean resources)

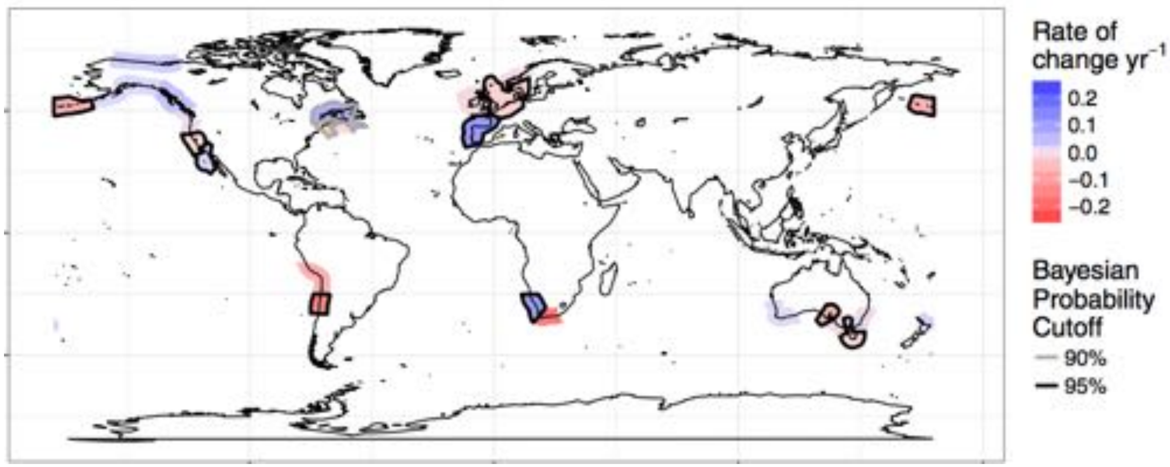
Coral conservation at the expense of macroalgae?

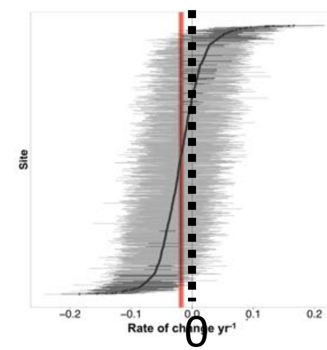
Global changes in corals



Globally threatened

Global changes in macroalgae (kelps)





Weak decrease

Krumhansl et al. 2016 PNAS

Tropicalized temperate zone can have conservation potential for corals (Yamano *et al.* 2011; Beger *et al.* 2014 Div. Dist.) at the expense of macroalgae under climate warming

This study shows ocean current transport and impacts of herbivorous fishes and corals enhance community shift under climate warming

1. Reconstructing overall patterns of distribution range shifts in macroalgae, corals and impacts of herbivorous fishes in Japan

–> compiling historical observation records from various literature sources (presence / absence)

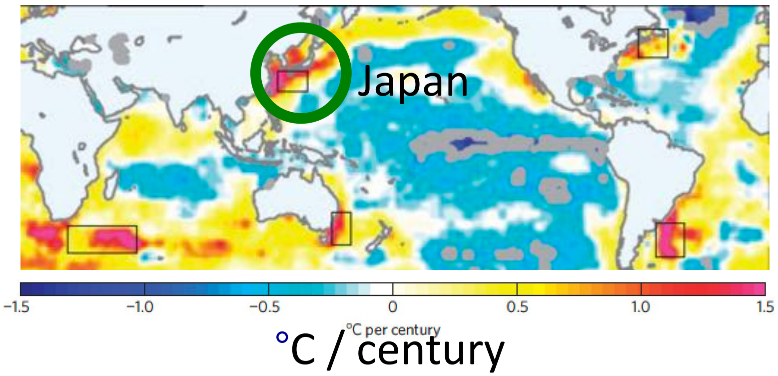
2. Modeling relative importance of temperature warming and current transport in community shifts from macroalgae-to-corals

–> using “climate velocity” informed with ocean current transport

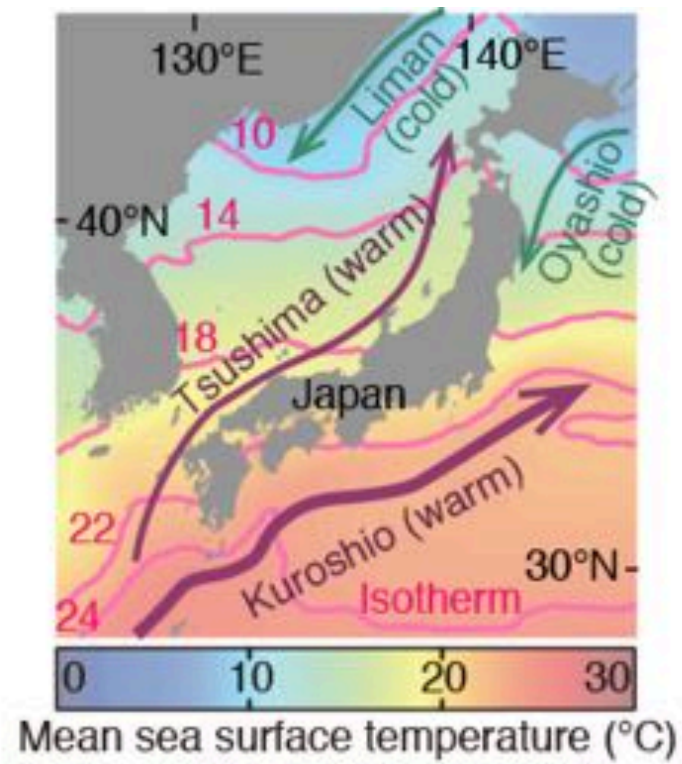
3. Estimating relative importance of herbivorous impact (indirect) and coral colonization (direct) as the process of the community shift

–> using a hierarchical Bayesian inference via MCMC

Unique advantages of Japanese coastal ecosystems



Rapid warming by boundary currents
(Wu *et al.* 2012 Nature CC)



1. Rapid warming by boundary current

–> large potential for tropcalization

2. Japanese archipelago stretches across 3,000 km from tropical to subarctic zone

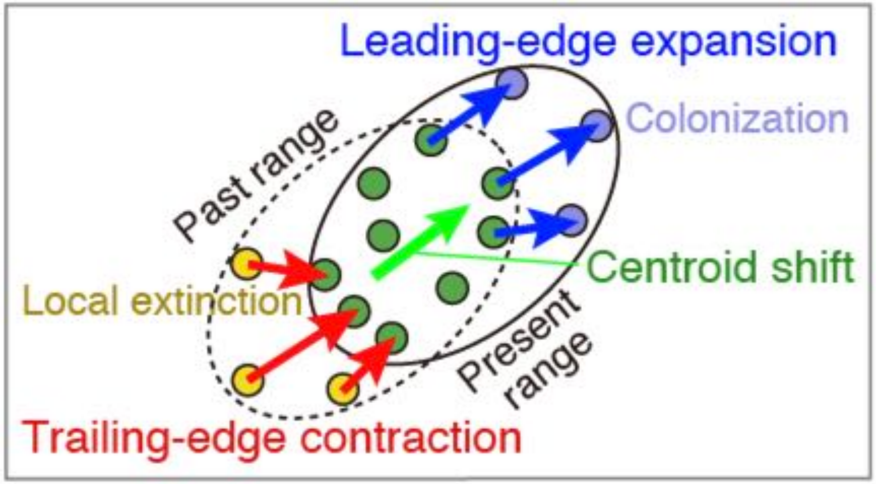
–> including many range edges of species distribution

3. Two warm currents encircling Japan provide various directional transports for marine organisms

–> ideal condition to disentangle effects of warming & current transport

4. Many distribution records on macroalgae and corals are available since early 20th century

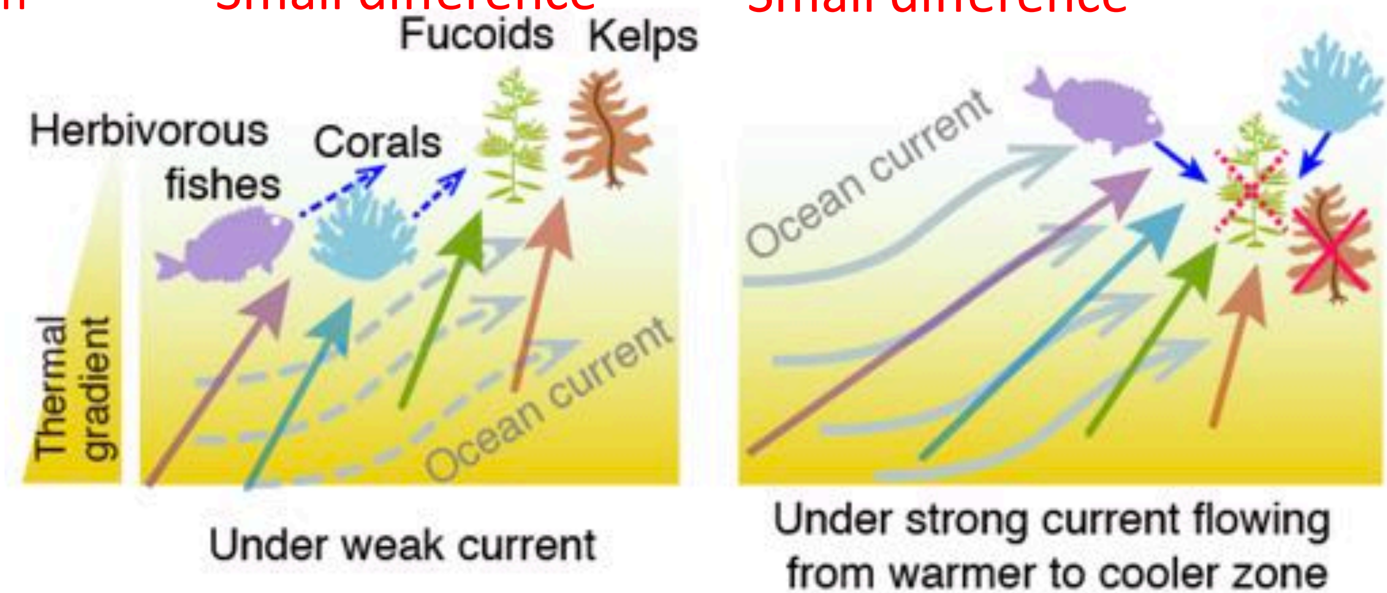
Expectation in range shift process



	Adult mobility	Larval / spore duration
Herbivorous fishes	Motile	Month
Corals	Sessile	Days–month
Fucoids	Sessile (+Drift with float)	hours
Kelps	Sessile (+Drift)	hours

Expansion, Centroid shift — Small difference — Difference increases with current

Contraction — Small difference — Small difference

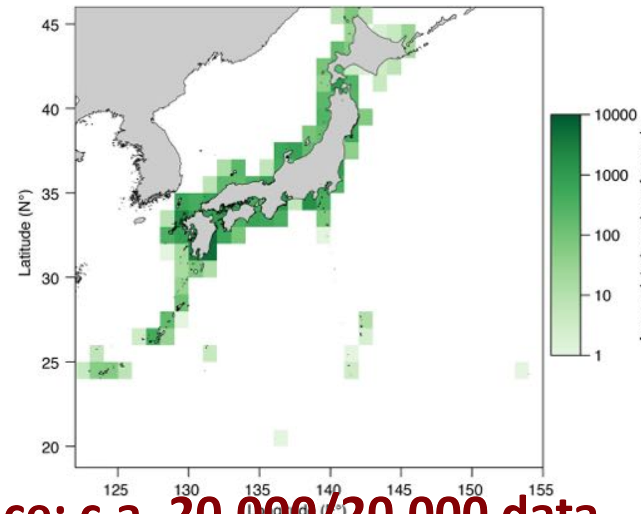


Compiling historical records –> Reconstructing range shifts

439 literature sources mainly 1950s–2010s

- Kelps : 7 species
- Fucoids (*Sargassum*) : 23 species
- Corals : 12 species
- Herbivorous fishes : 3 species (overgrazing)

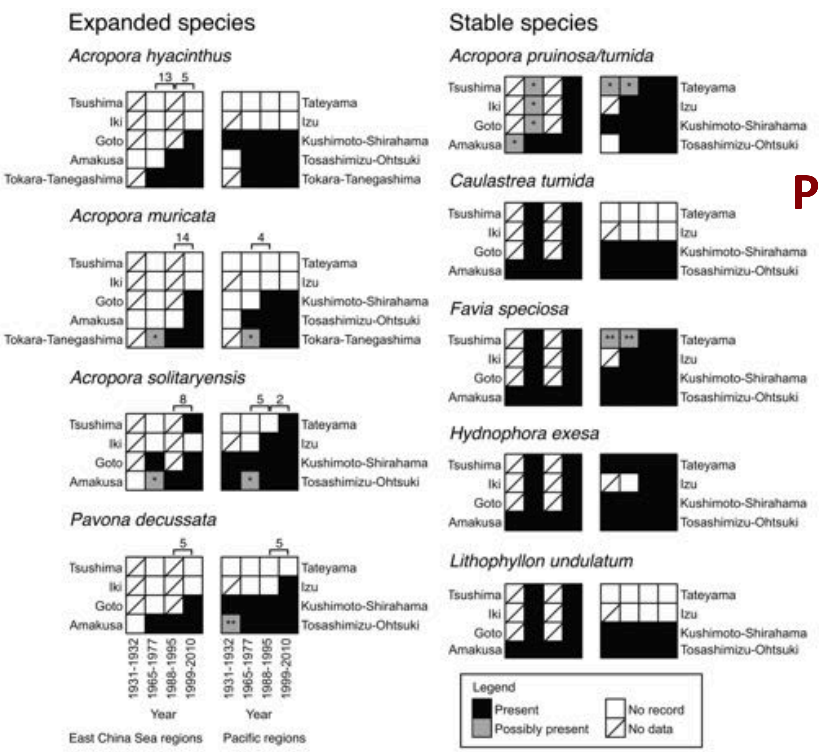
Presence / absence of
86 species kelps & fucoids
Kumagai *et al.* (2016) Ecol. Res. (Data paper)

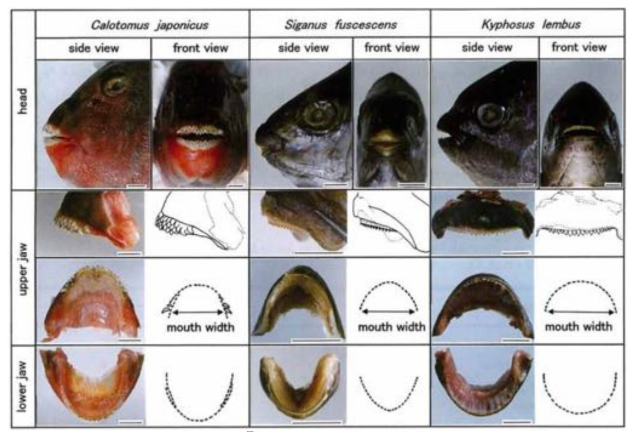


Accum. num. of records

Presence/absence: c.a. 20,000/20,000 data

Range shifts of corals (Yamano *et al.* 2011 + this study)



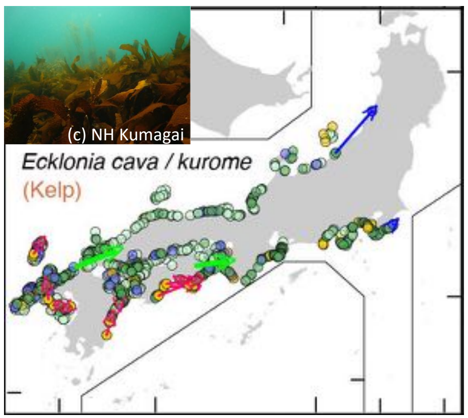


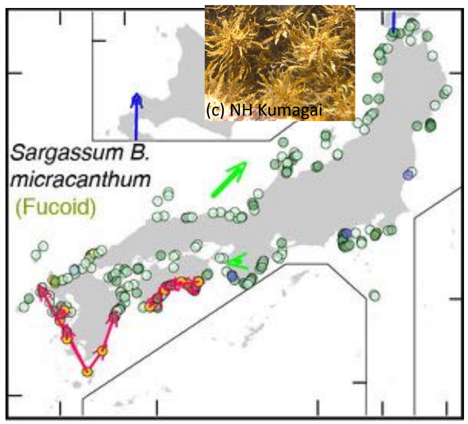
Overgrazing by 3 herbivorous fishes (This study)

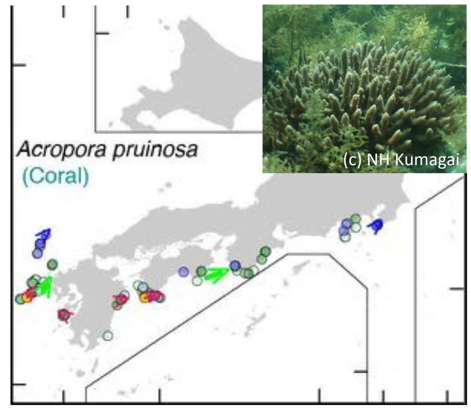
<– (Kiriyama 2006 Bull. Nagasaki Fish. [in Japanese])

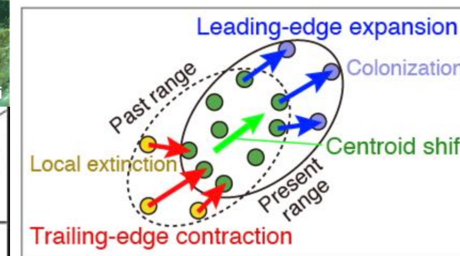
Examples of identified range shifts (7/45 species)

Temperate specis







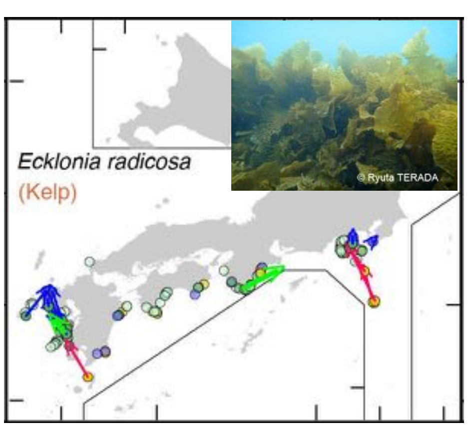


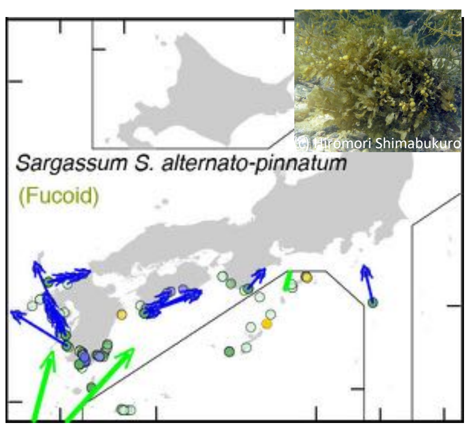
Kelps

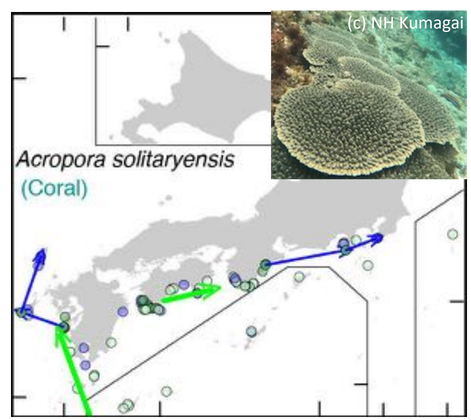
Fucoids

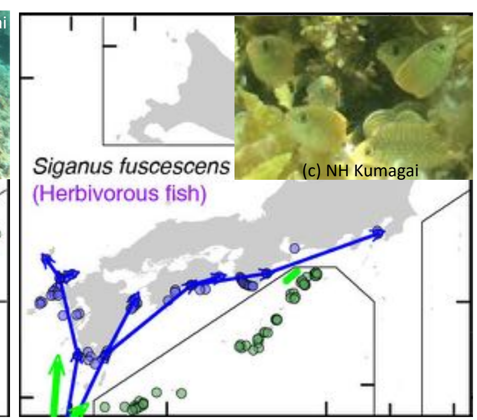
Corals

Herbivorous fishes (overgrazing)







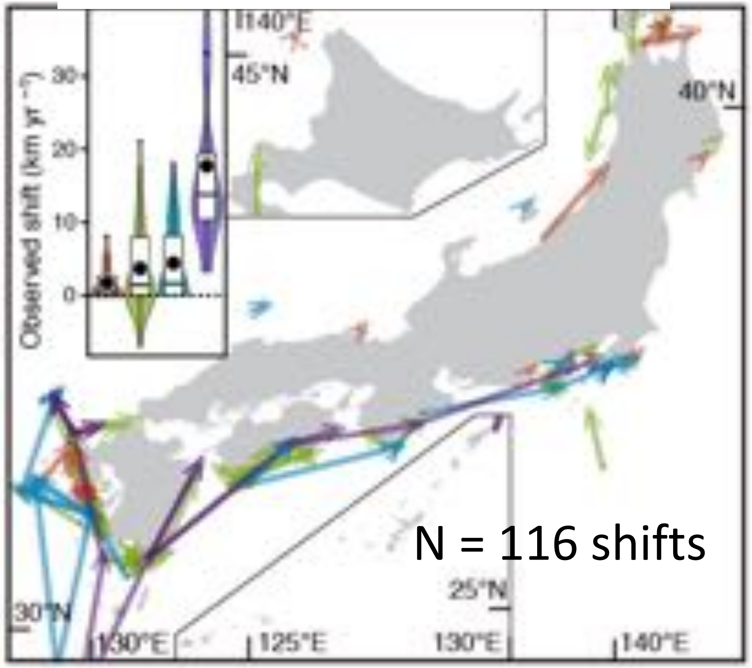


Subtropical – tropical species

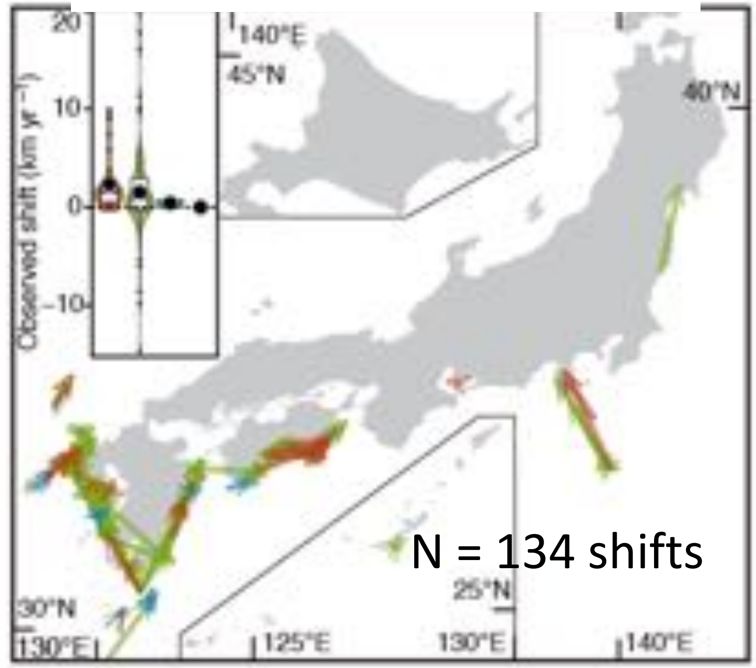
- Presence in multiple periods
- Presence in a single period
- Colonisation
- Local extinction
- Centroid shift
- Leading edge expansion
- Trailing edge contraction

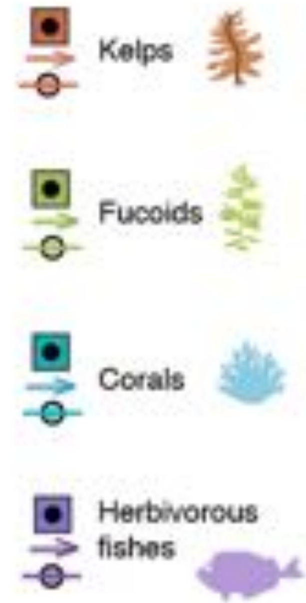
Summary of identified range shifts

Leading edge expansion

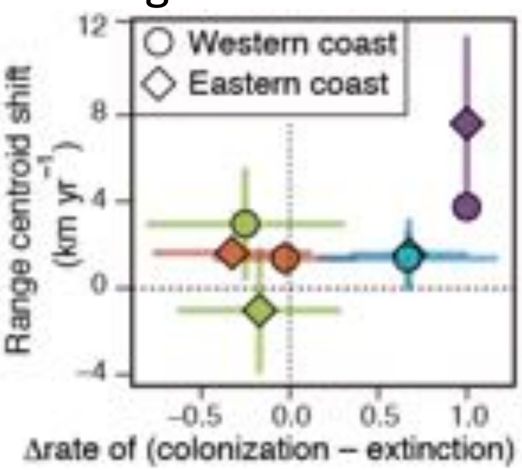


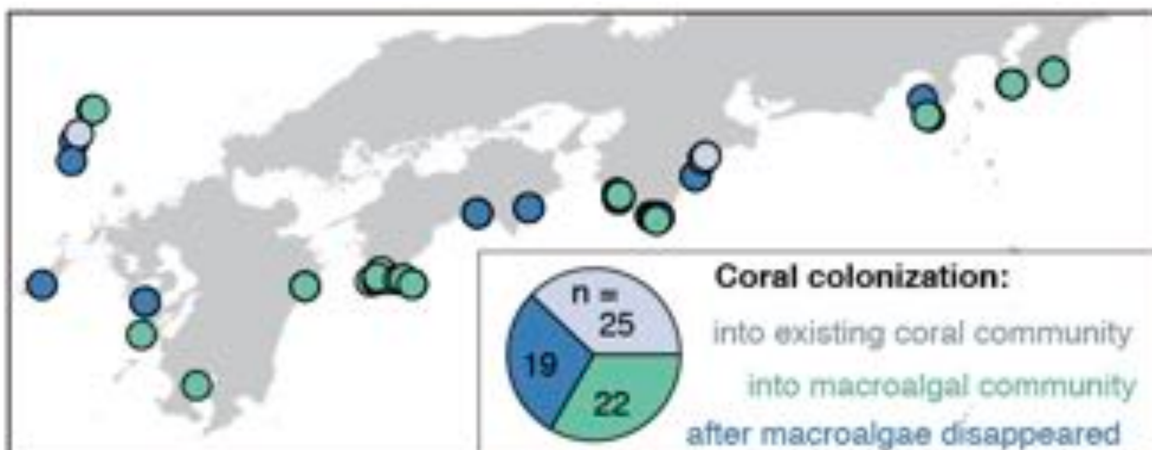
Trailing edge contraction





Range centroid shifts

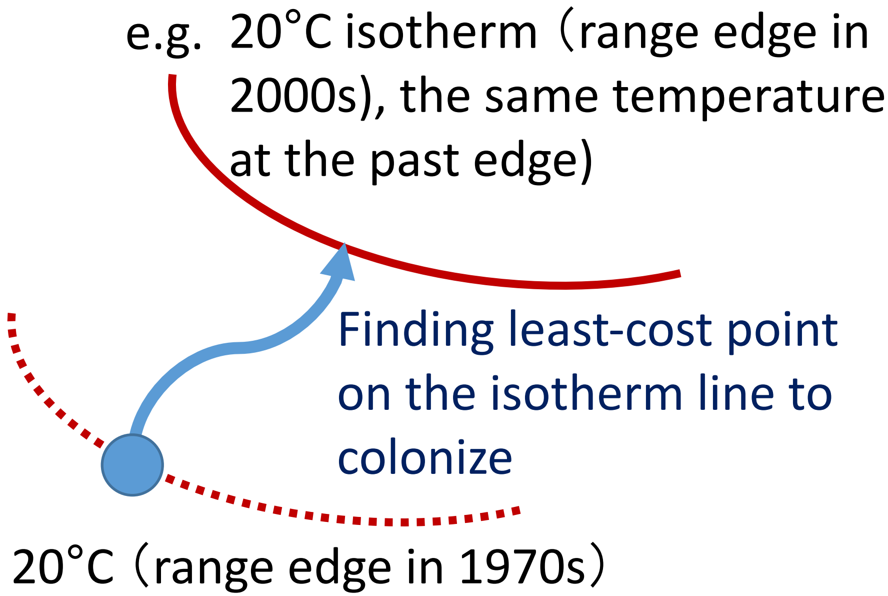




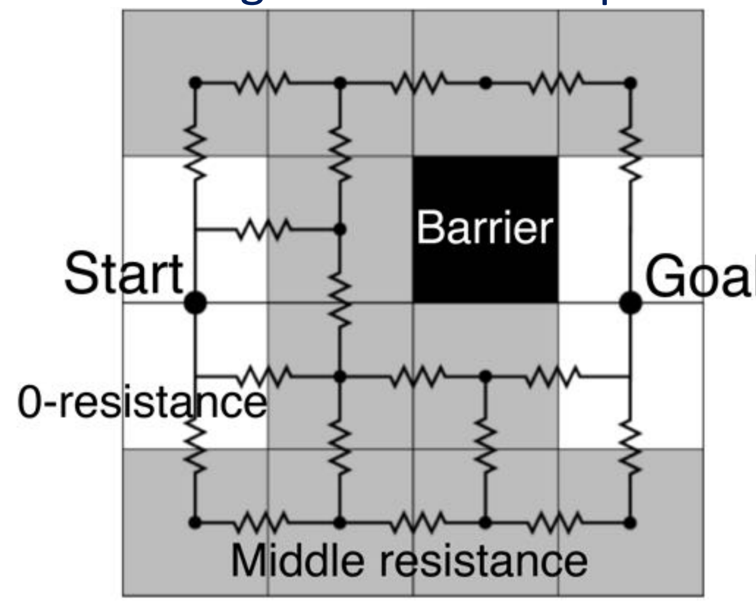
Modeling range shift using a process-based model

Climate velocity trajectory model

（Burrows *et al.* 2011 Nature)



Taking minimum cost path



Circuit theory

（McRae *et al.* 2006 Mol. Ecol.）

Climate velocity = length of least-cost path / years

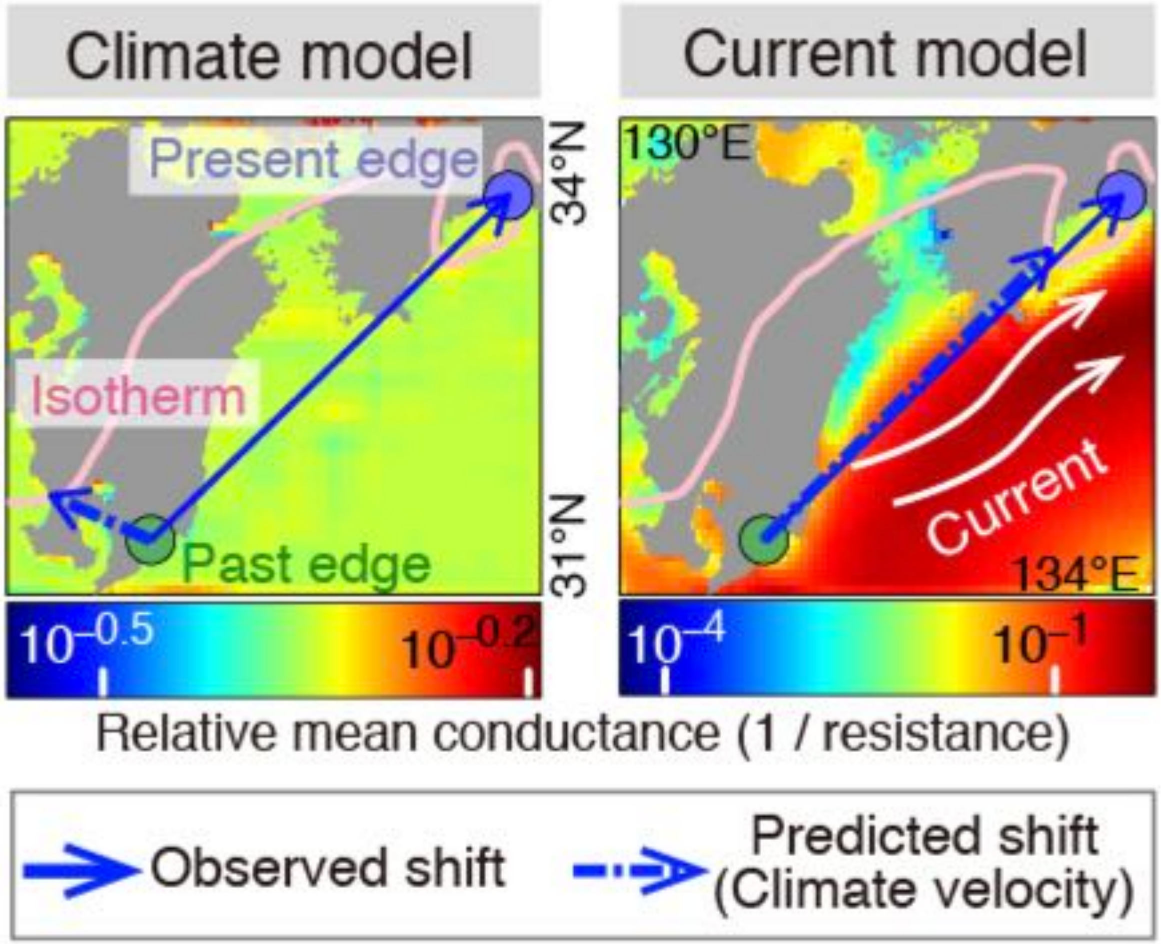
Small resistance (large conductance): shifts following current

Large resistance (small conductance): shifts against current

Current conductance = 1 / current speed

Extending coastal version of Burrows's model to represent not only climate warming also transport by ocean current (directional transport with current velocity)

Modeling range shift using a process-based model



We expected the model including current transport explain range shift from past to present edge better than climate only model

Relative importance of current transport ***w*** was estimated using a Bayesian inference

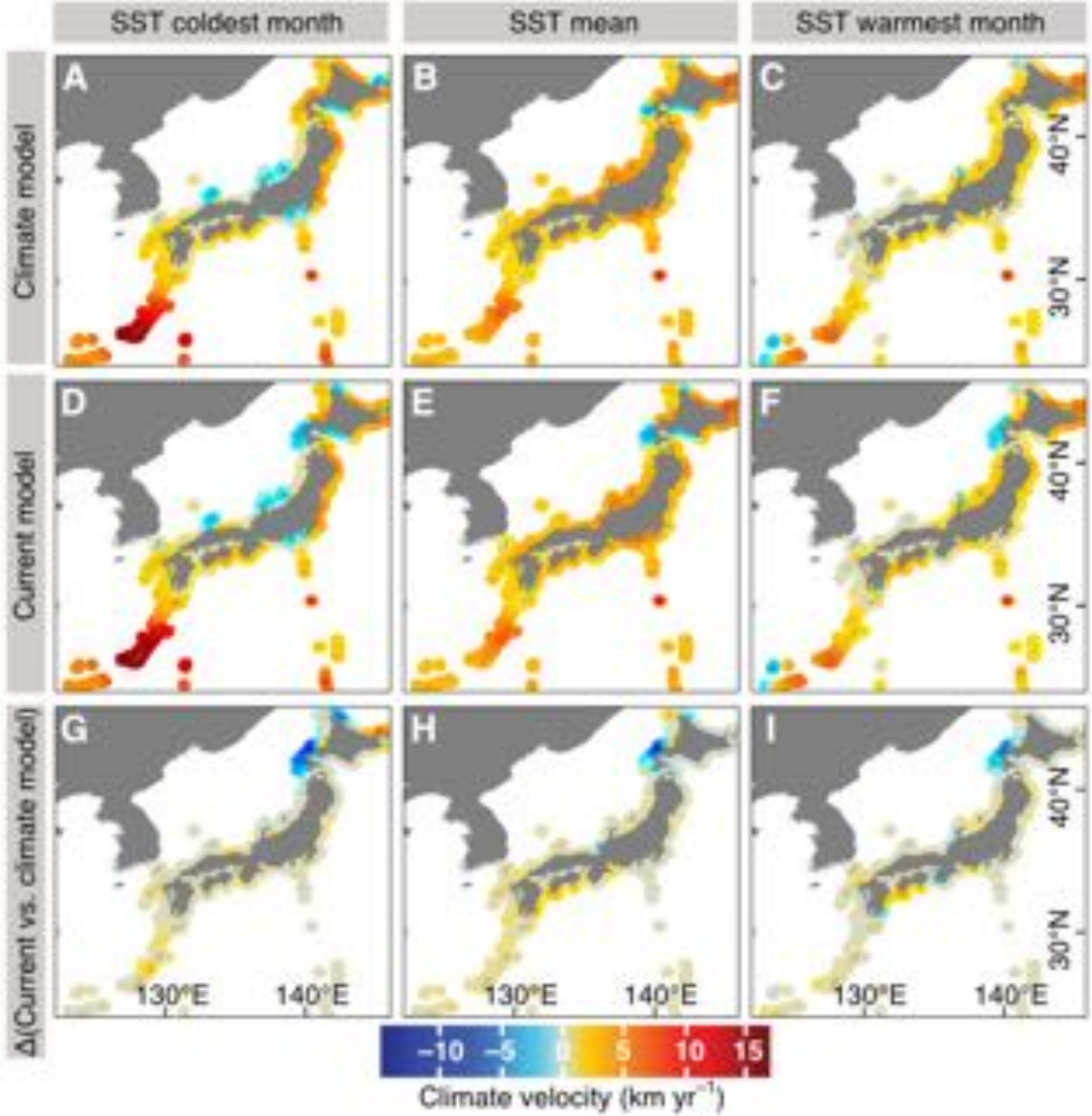
$\text{Conductance}_{\text{optimum}\ s,g} = (1 - \boldsymbol{w})\ \text{Conductance}_{\text{temperature}\ s} + \boldsymbol{w}\ \text{Conductance}_{\text{current}\ g}$

s: species; : *g*: taxa group (kelp, fucoids, corals, fishes);

using one of 4-levels temperature indices (min – mean for expansions, max – mean for contractions)

using current data of different season (macroalgae: throughout; corals, fishes: early summer)

Map of explanatory variable (climate velocity)

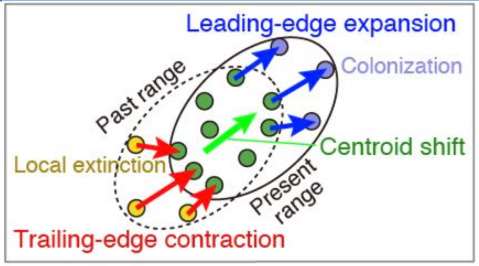


Example of changes 1970–2009

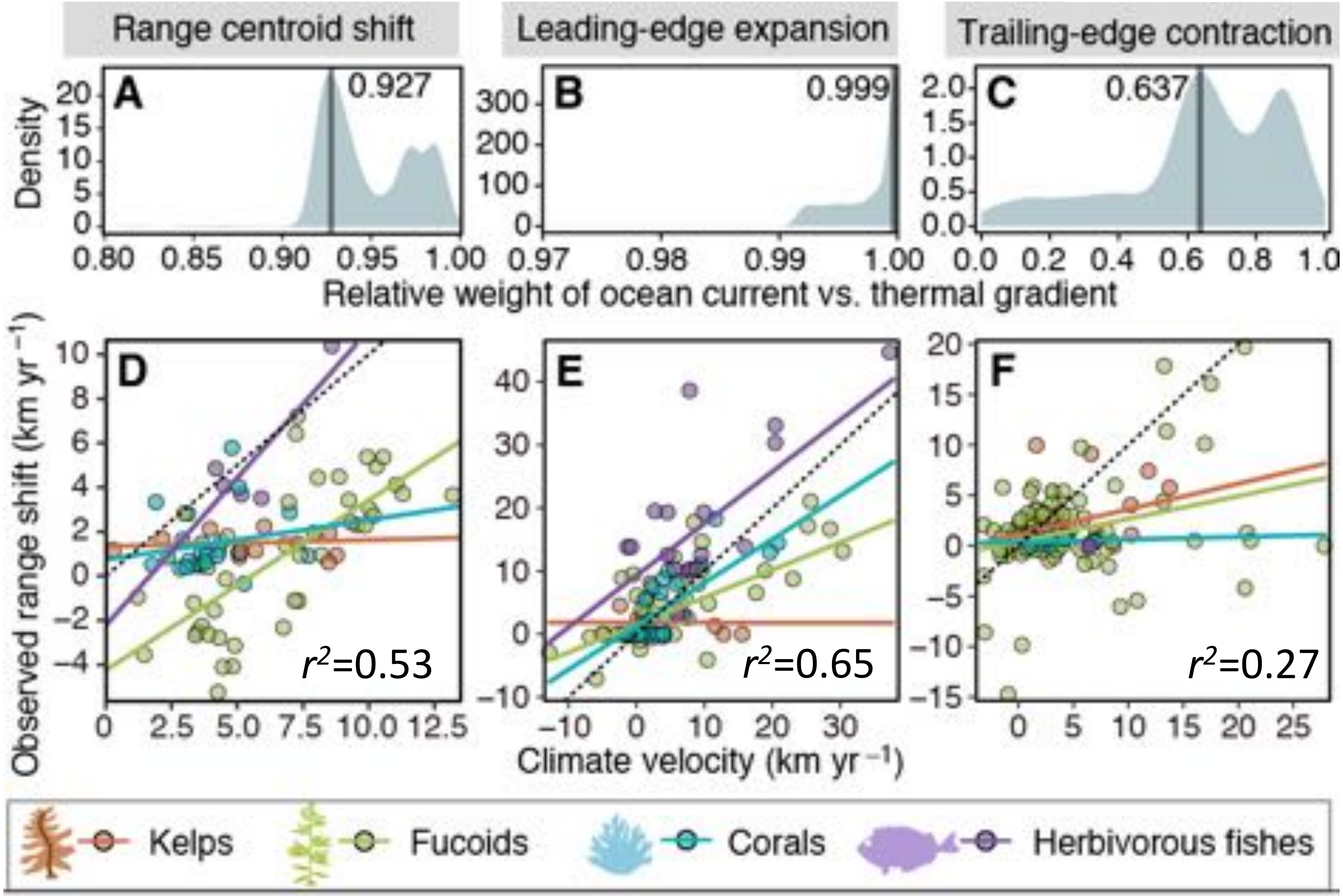
Positive differences in south western area

Analyzing effects of warming and current transport

A Bayesian inference of relationship between observed and predicted shift rates



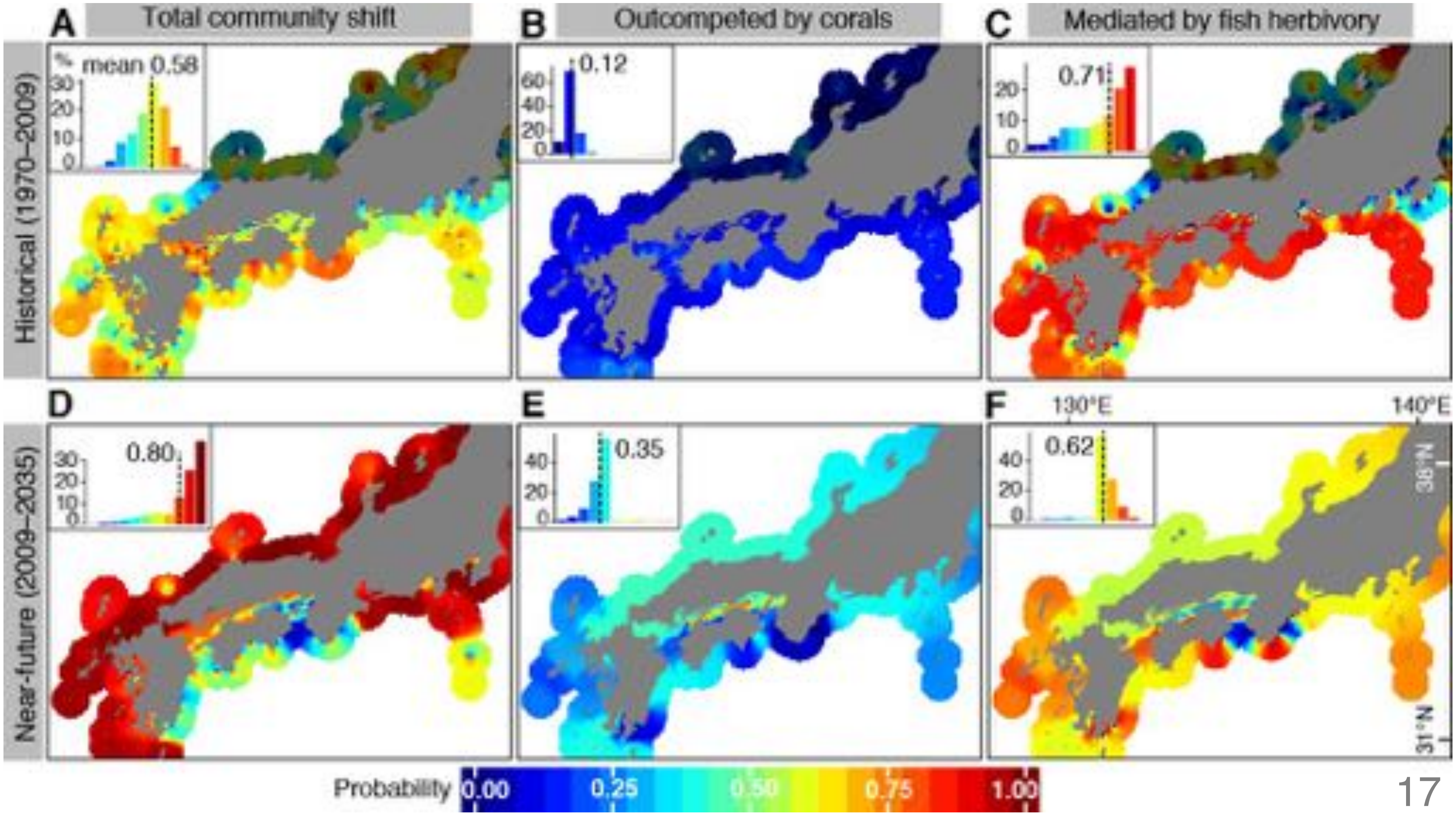
Observed shift$_i$ ~ $\alpha_{g,(s)} + \beta_g$ *Climate velocity*$_i$



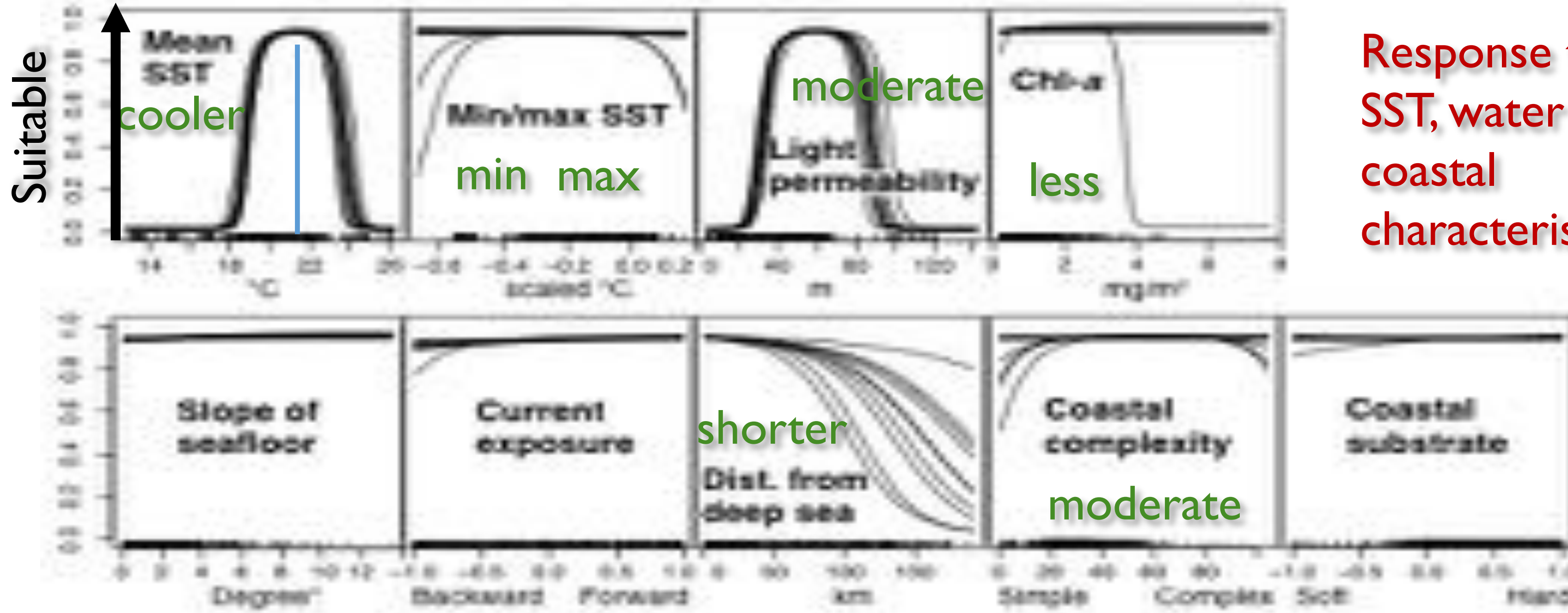
Predicted potential probability of community shift & driving processes

a Bayesian inference on predicted shift rates against climate velocity
(MCMC samples of target processes/total)

Condition:	Community shift from macralgae to corals (total of all shift processes)	Processes of macroalgae-coral shift: direct process (competition) corals > fishes | algal contract	Processes of macroalgae-coral shift: indirect process (herbivory) corals < fishes | algal contract



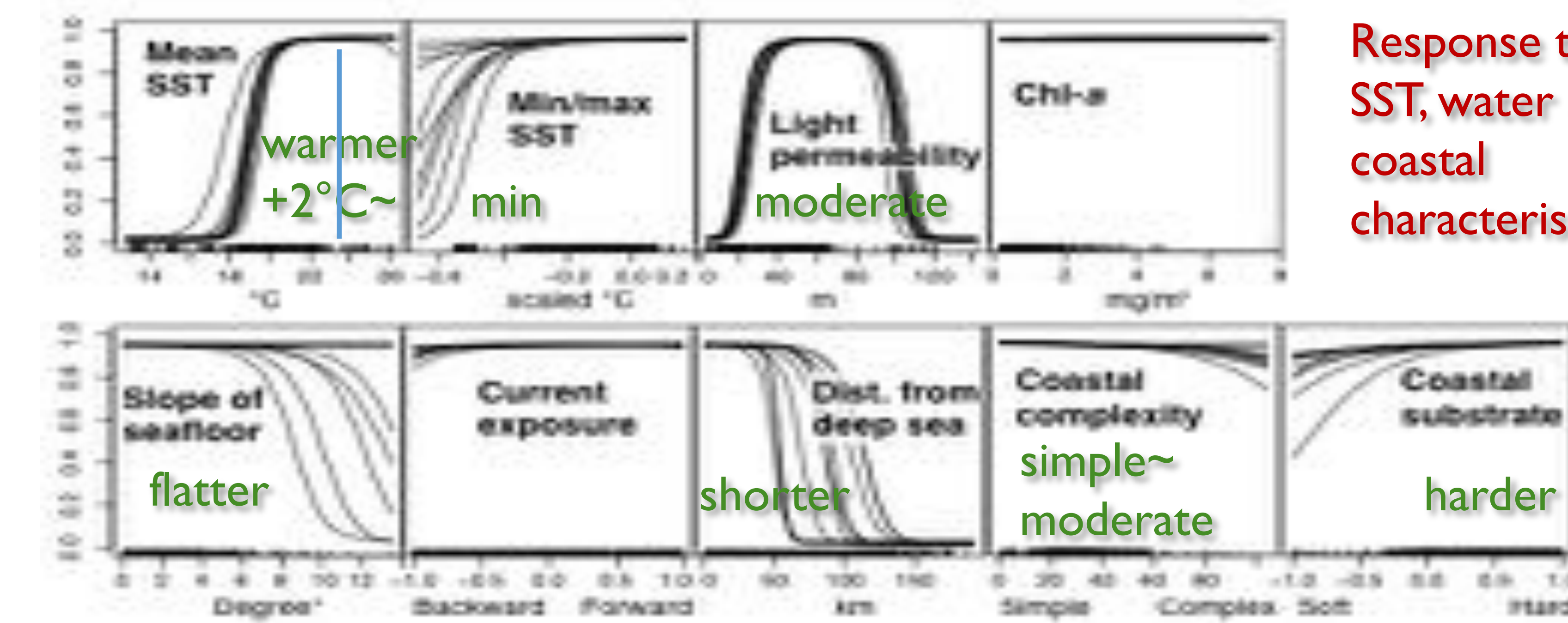
Temperate species



Response to SST, water & coastal characteristics

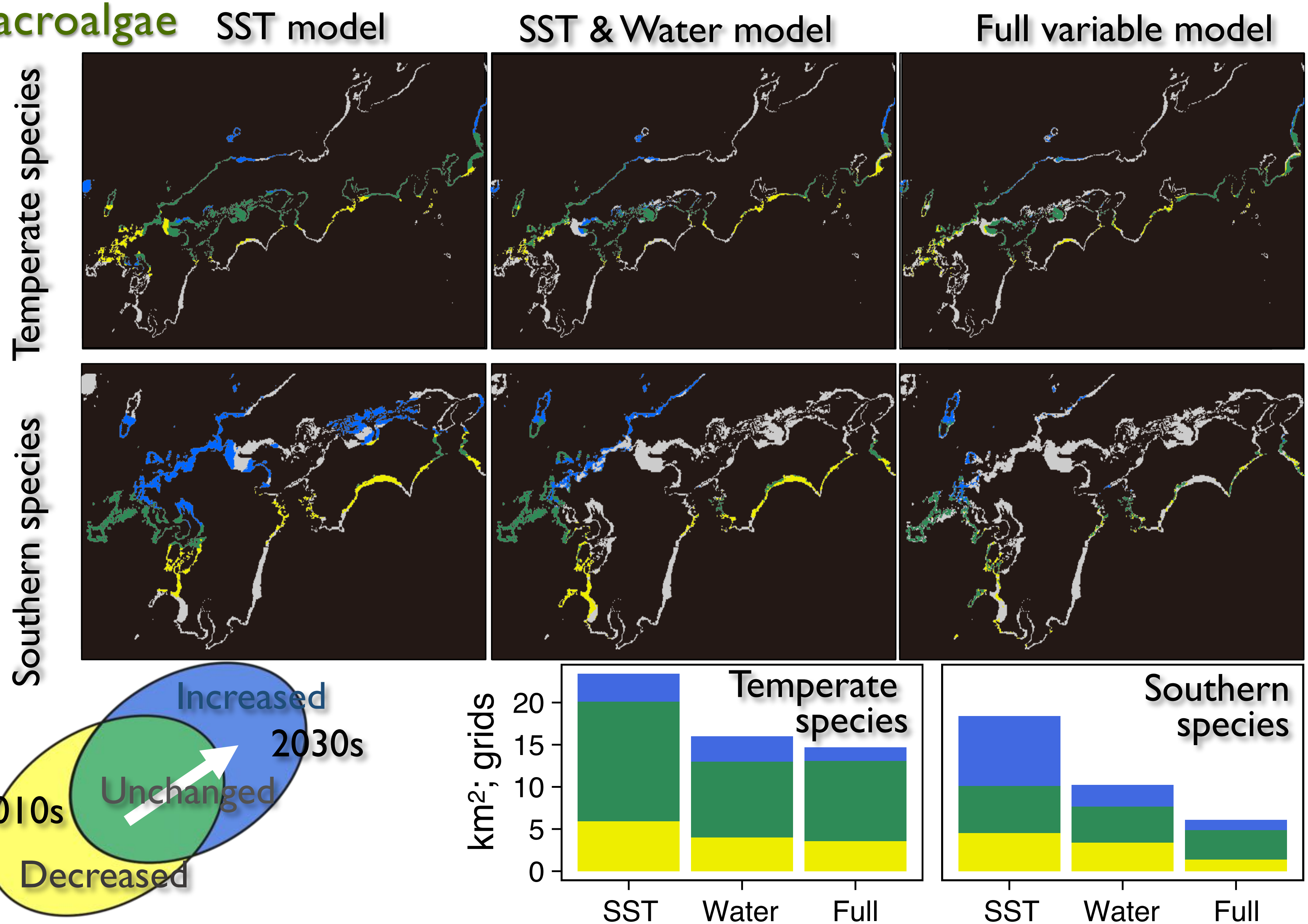
Response to environmental variables

Southern species



Response to SST, water & coastal characteristics

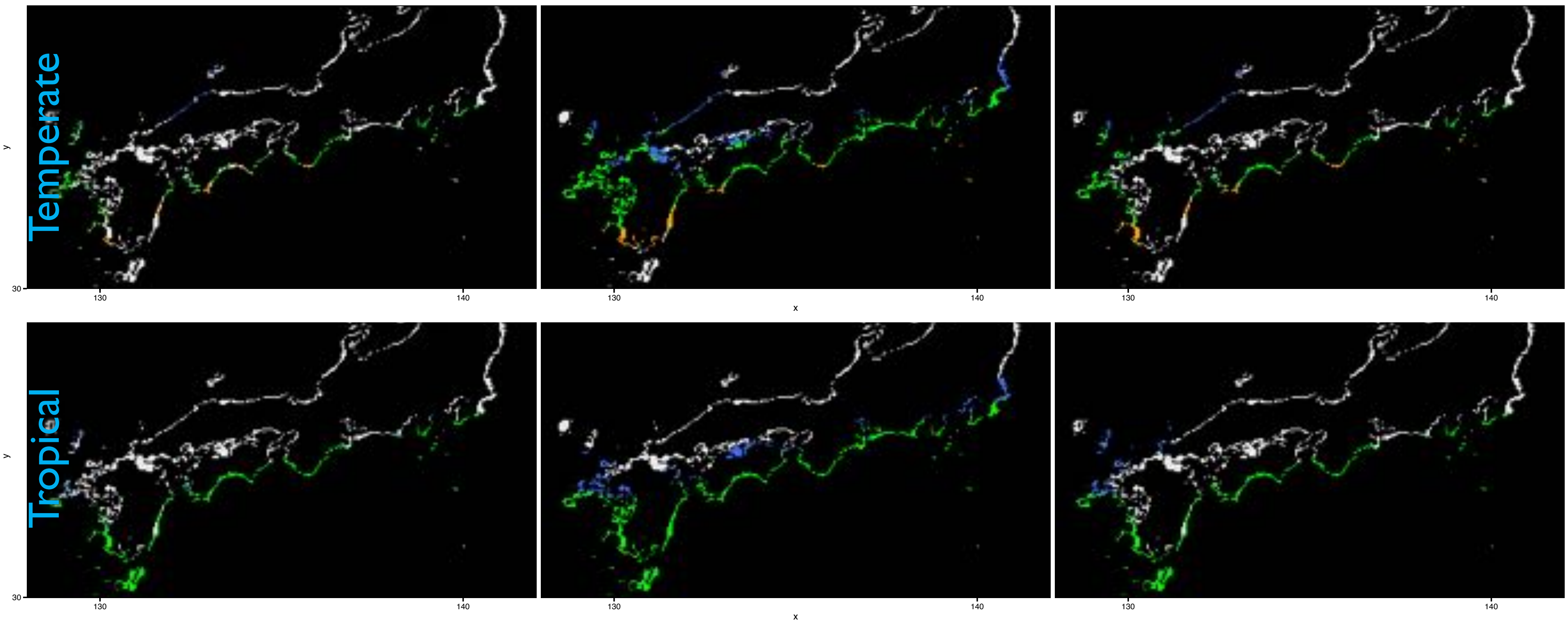
Macroalgae

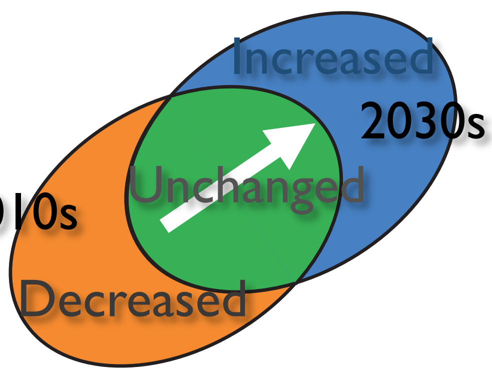


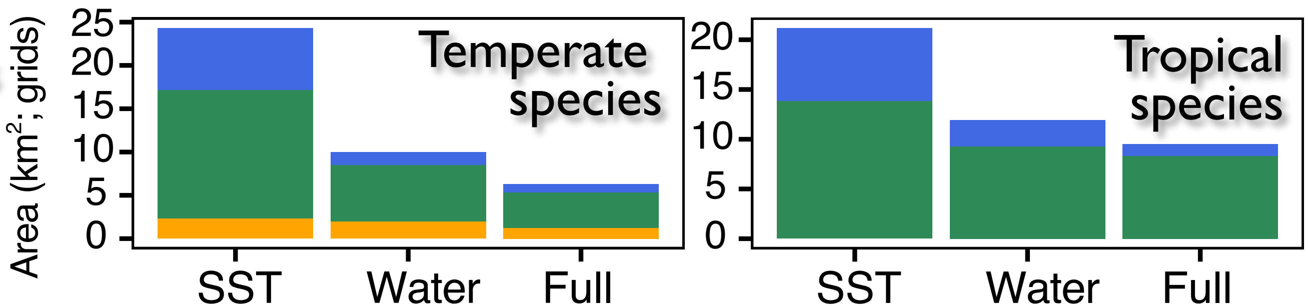
- SST model, SST & Water model overestimated habitable area and habitat changes
- Temperate sp.: Decrease > Increase; Southern sp.: Decrease = Increase

Corals

SST model | SST & Water model | Full variable model







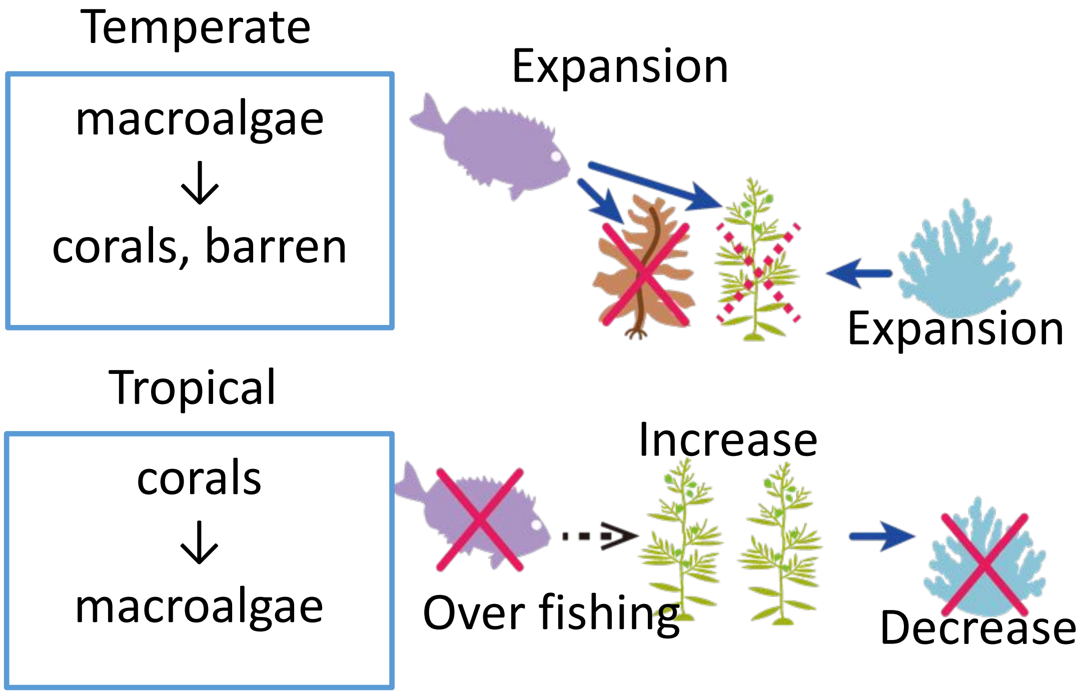
- SST model, SST & Water model overestimated habitable area and habitat changes
- Temperate sp.: Decrease ≈ Increase; Tropical sp.: Decrease << Increase

Adaptation strategies in conserving both of macroalgae and corals

Proactive conservation strategies:

- Assisted migration/evolution
- Management of herbivorous fishes (should be used as seafoods)
- Adaptation to changed ecosystem services

Overfishing in tropical
–> Increase of algae
& decrease of corals
Bellwood et al. (2004) Nature



Adaptation gap between community shifts and coastal uses

Ongoing field-based study for ecological processes and coastal uses

Aquaculture: whole area

- Community shift from macroalgae to corals within 90 km of range
- Macroalgae — diving fishery
- Corals — leisure diving

- Adaptation of coastal uses is slower than community shift
- Intense herbivory drive community shift but few management of herbivores

Feeding experiment for herbivory

Take home messages

1. We described overall patterns of distribution range shifts in macroalgae, corals and impacts of herbivorous fishes in Japan

2. We showed how current transport is important to explain community shifts from macroalgae-to-corals

3. We estimated potential probability of the community shift and the probability might increase in near-future

4. Herbivorous impact (indirect) were more probable process than coral colonization (direct), but the importance of the direct process might increase in near-future

5. Proactive managements might conserve both of macroalgae and corals, but adaptation gap between community shift and coastal use