

Coral genetic diversity and hidden species boundaries

The University of Tokyo
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My research interests

- **Conservation of ecosystems:** early life ecology (larval dispersal, reproductive timing, fertilization rate etc) of coral reef invertebrate species.
- **Understanding biodiversity:** speciation of coral reef invertebrate species

1) Review of Marine Protected Areas by Integrated Approach in Japan

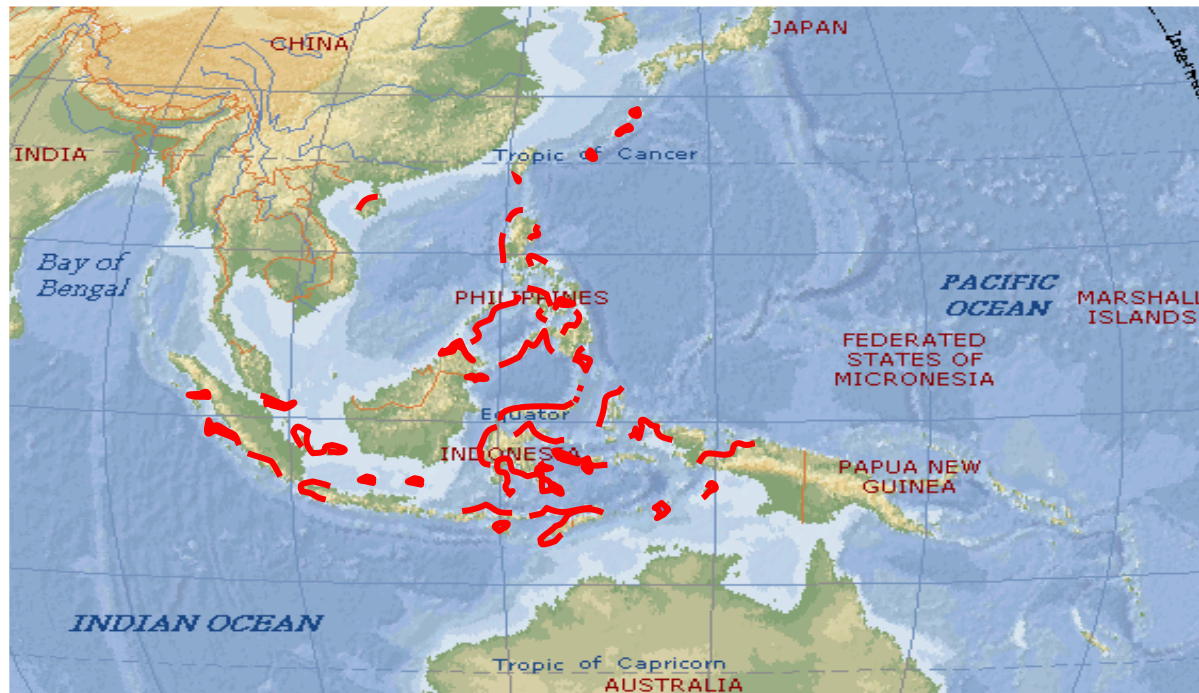
Coral reefs

Amazon in the Sea

$< 0.2\%$

~ 30%

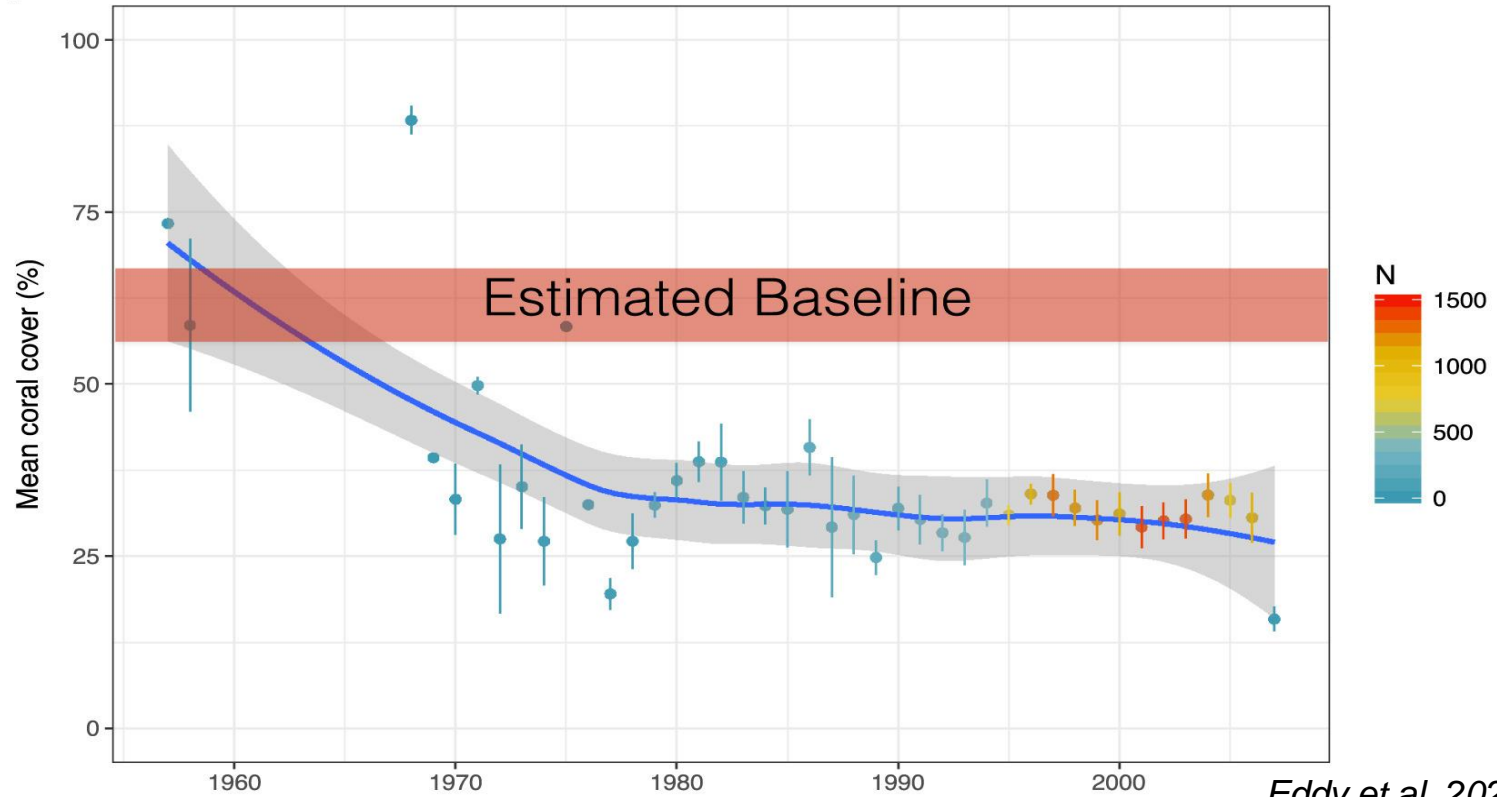
More than half of the coral reefs are highly threatened



Pandolfi et al.(2003) Science

Global coral cover has halved since the 1950s

A



Eddy et al. 2021 One Earth

At least 63% of the total number of marine species lost due to coral decline

A background map showing Southeast Asia, the Pacific Ocean, and parts of Australia and China. Labels include CHINA, JAPAN, PHILIPPINES, PACIFIC OCEAN, MARSHALL ISLANDS, INDONESIA, PAPUA NEW GUINEA, AUSTRALIA, and Tropic of Capricorn. The Bay of Bengal is also labeled.

The tenth meeting of the Conference of the Parties of
The Convention on Biological Diversity(CBD COP 10)
(2012)

Aichi Biodiversity Targets 10 the multiple
anthropogenic pressures on coral reefs impacted by
climate change or ocean acidification are minimized,
so as to maintain their integrity and functioning.

Pandolfi et al.(2003) Science

COP15 Global Biodiversity Framework

Ensure and enable that by 2030 at least 30 per cent of terrestrial, inland water, and of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem functions and services, are effectively conserved and managed through ecologically representative, **well-connected and equitably governed systems of protected areas** and other effective area-based conservation measures, recognizing indigenous and traditional territories, where applicable, and integrated into wider landscapes, seascapes and the ocean, while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of indigenous peoples and local communities, including over their traditional territories.

Marine Protected Areas (MPAs)

*An area designated and effectively managed **to protect marine ecosystems, processes, habitats, and species**, which can contribute to the restoration and replenishment of resources for social, economic, and cultural enrichment.*

No take zone

marine parks

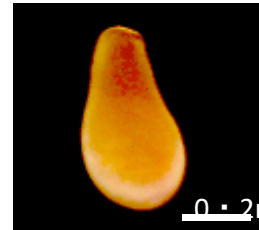
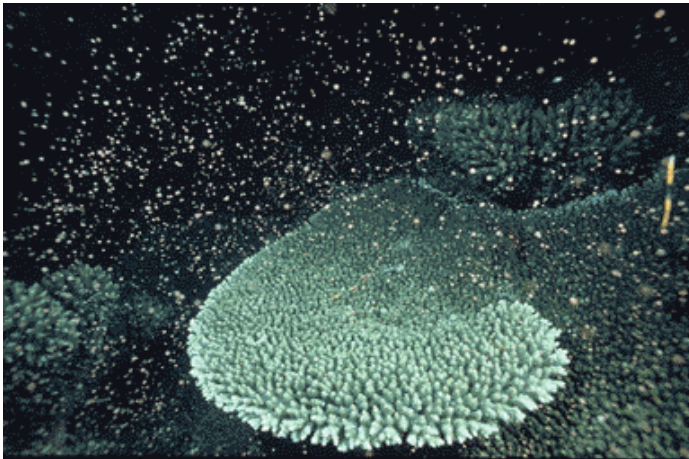
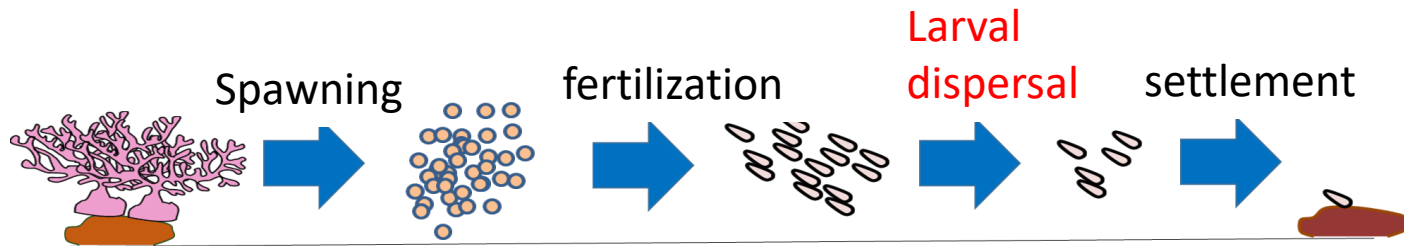
Locally managed areas

Challenge for designing effective MPAs

☆ ≡ Current MPAs designing in the world are not based on scientific evidence, without considering

- ①connectivity,
- ②genetic diversity,
- ③possible future habitat changes.

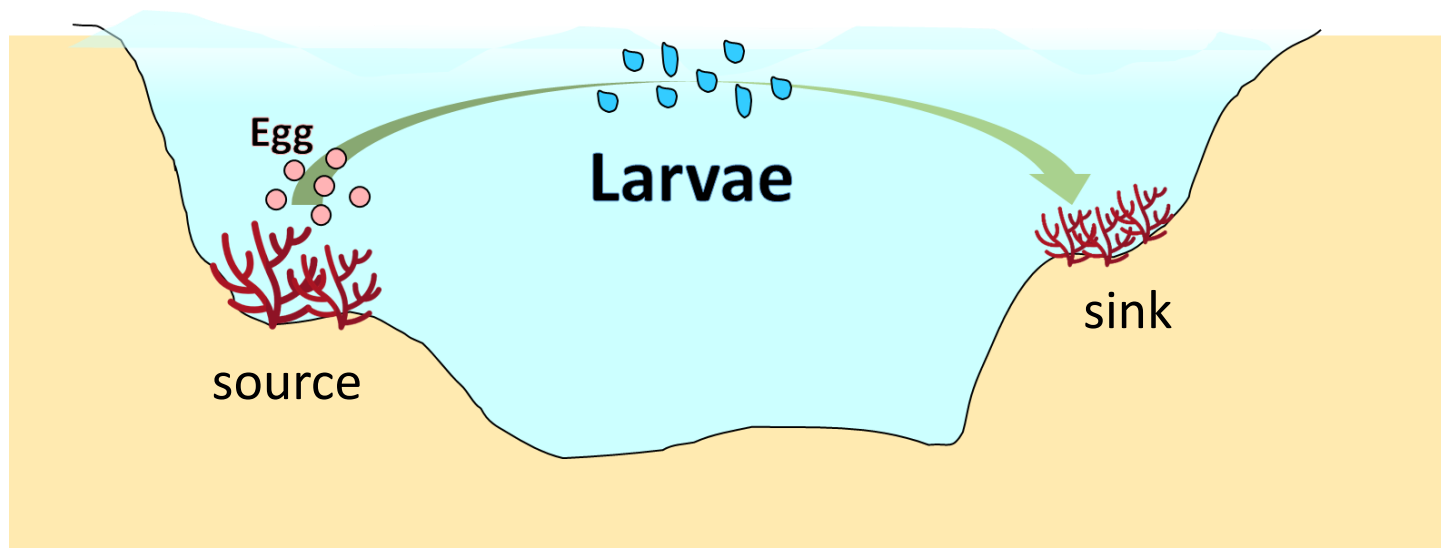
Life history of coral reef organisms



Although adults are sessile, eggs and larvae are dispersed in the ocean.

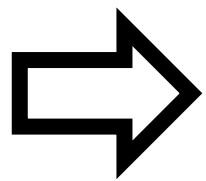
① Connectivity via larval dispersal*

*movement during planktonic period



Geographically separated populations are connected. Such connectivity network is important for maintaining populations

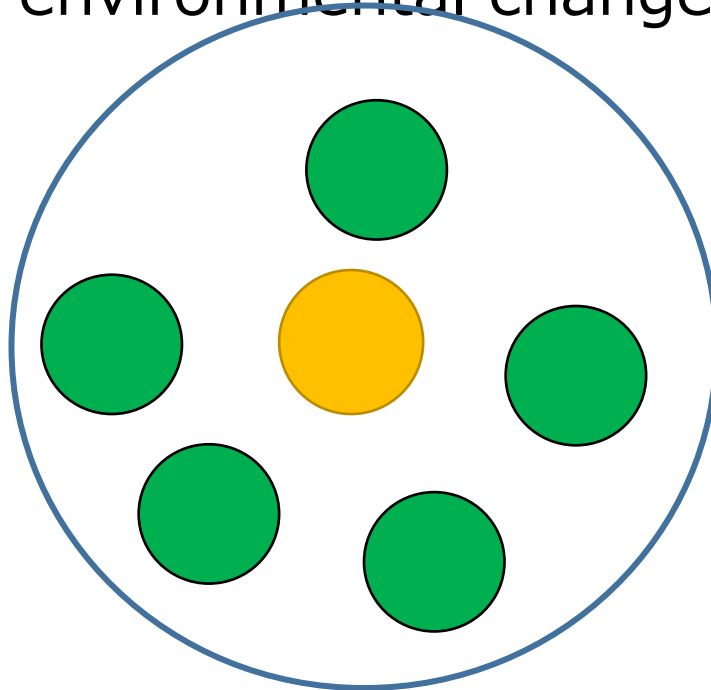
Isolated populations have higher risk of local extinction



Knowledge of connectivity is important for conservation and MPAs designing.

② Genetic diversity

Indicator for population persistence through environmental change



Extremely low genetic diversity

Importance of genetic diversity

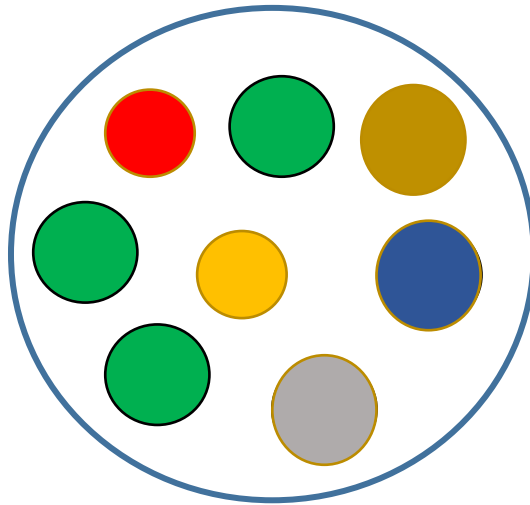


Higher risk of local extinction
Through environmental change
(climate change etc)

The diagram consists of a large blue circle representing a population. Inside this circle, there is a single yellow circle, which represents an individual. The text is centered over the yellow circle.

Population with low genetic diversity

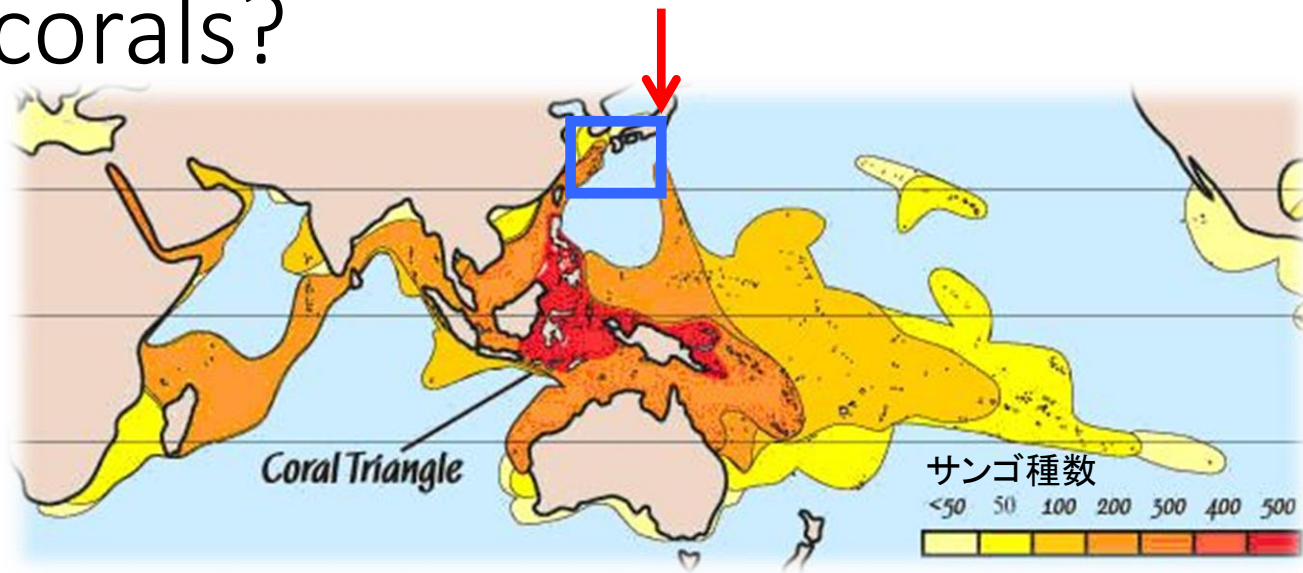
Population with high genetic diversity has higher chance of survival



Genetic diversity is the basis of biodiversity, evolution of species, population persistence.

③ Possible future habitat changes

What is happening in the northernmost distribution of corals?

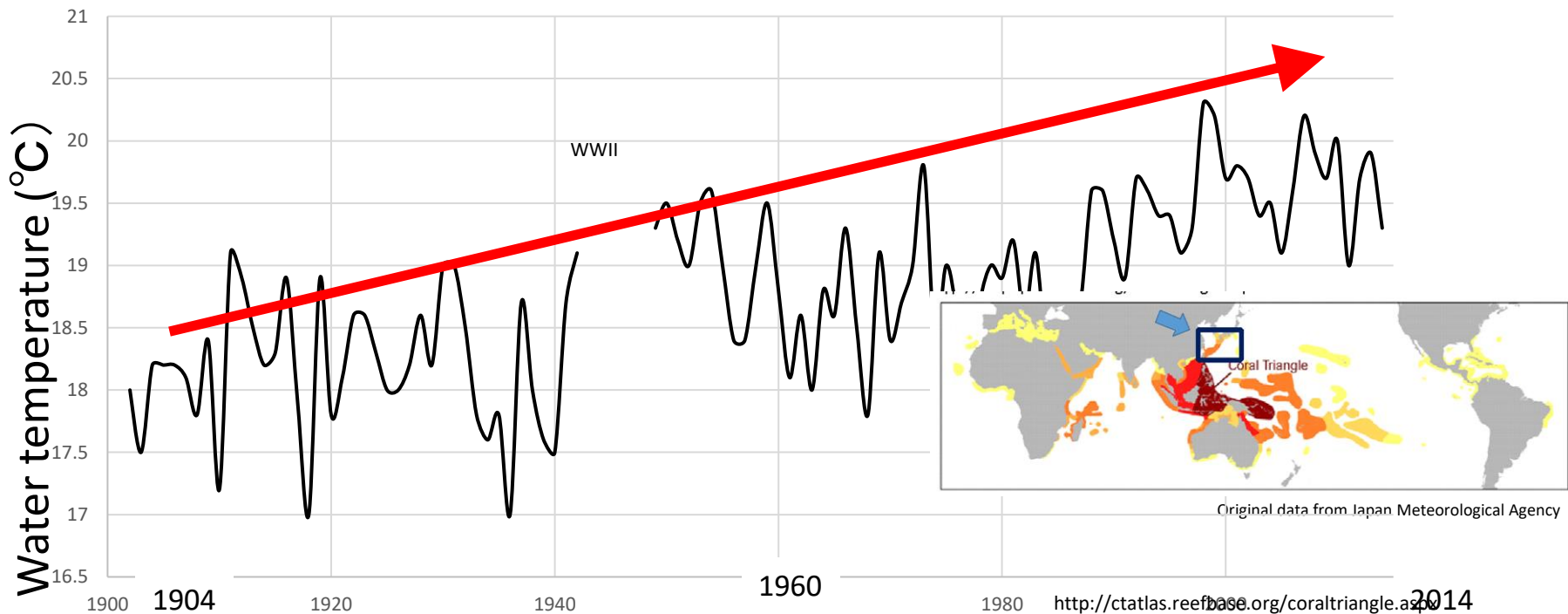


<http://ctatlas.reefbase.org/coraltriangle.aspx>

The seawater temperature rise in the waters near Japan is progressing at a rate more than twice as fast as the global average, allowing us to witness the forefront of global warming.

Along Kuroshio Current
World average

+1.21°C /100 years ($P < 0.01$)
+0.52°C/100 years



Transition of water temperature around Japan over 100 years

Tropicalization of Japan

1990s



Shikoku

Vergas et al 2014

Tropicalization of Japan

1990s



1997



Decrease of seagrass bed

Tropicalization in temperate Japan

1990s



1997



2000



desert

Tropicalization in temperate Japan

1990s



1997

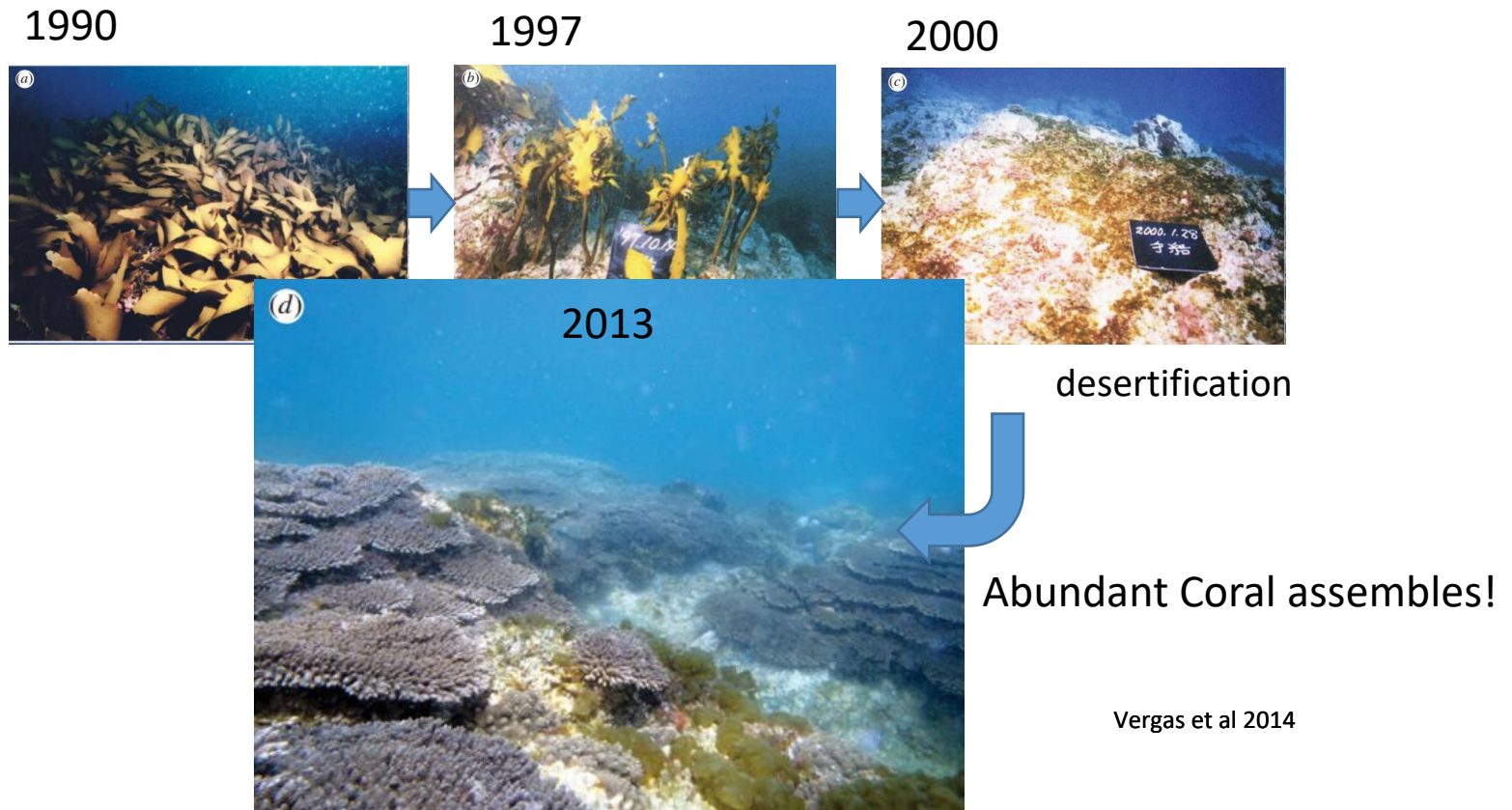


2000

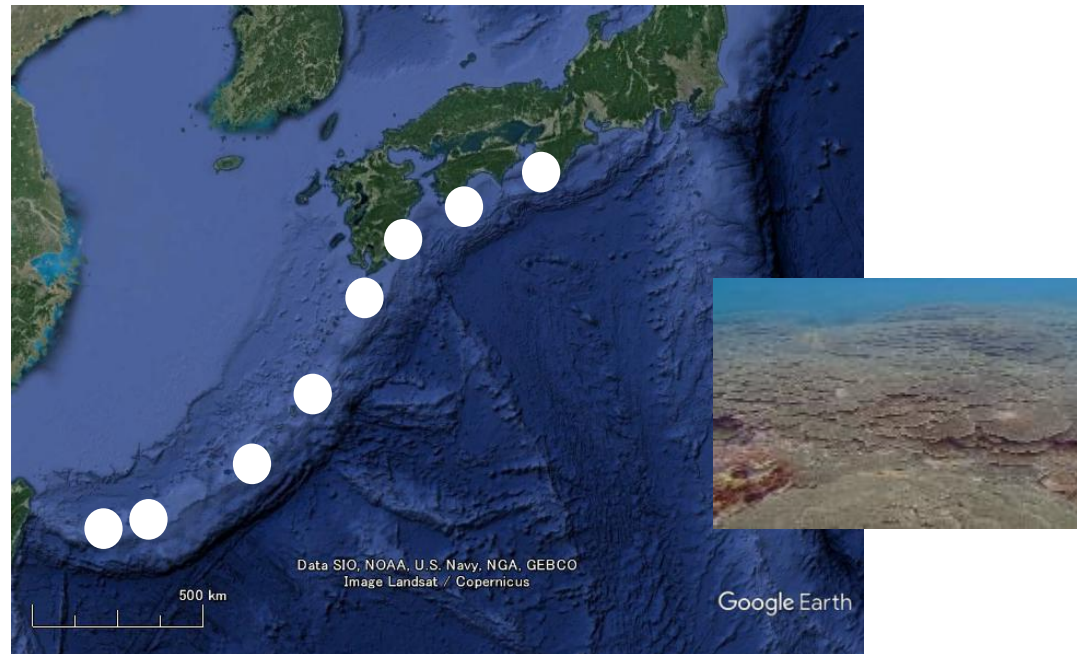


desertification

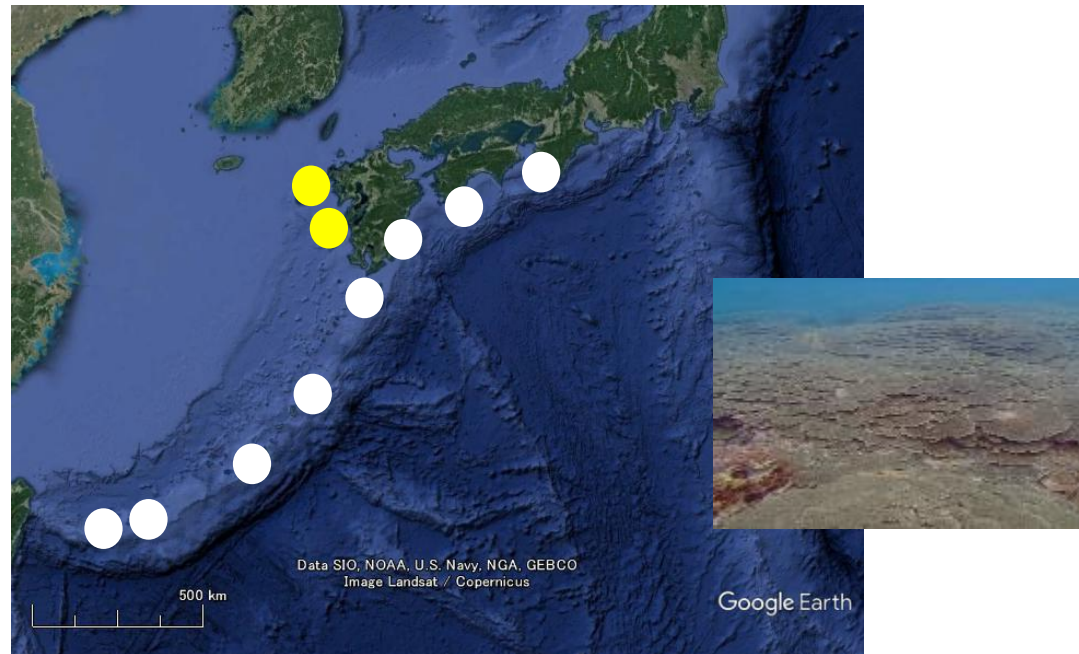
Tropicalization in temperate Japan



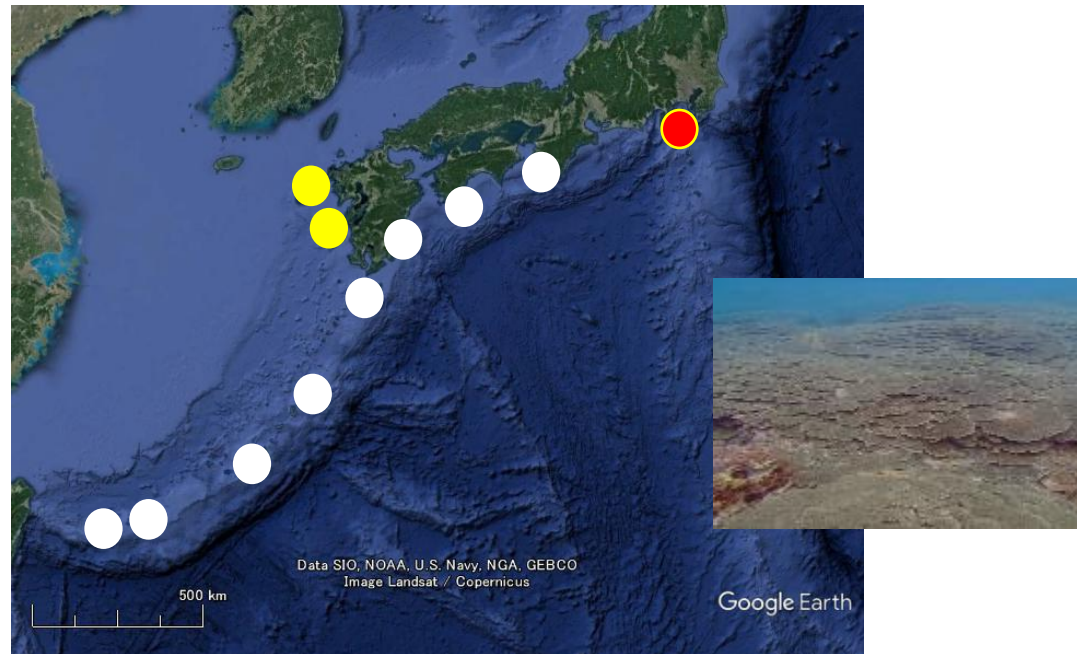
Distribution of coral *Acropora hyacinthus* before 1980s



Distribution of coral *Acropora hyacinthus* 2000



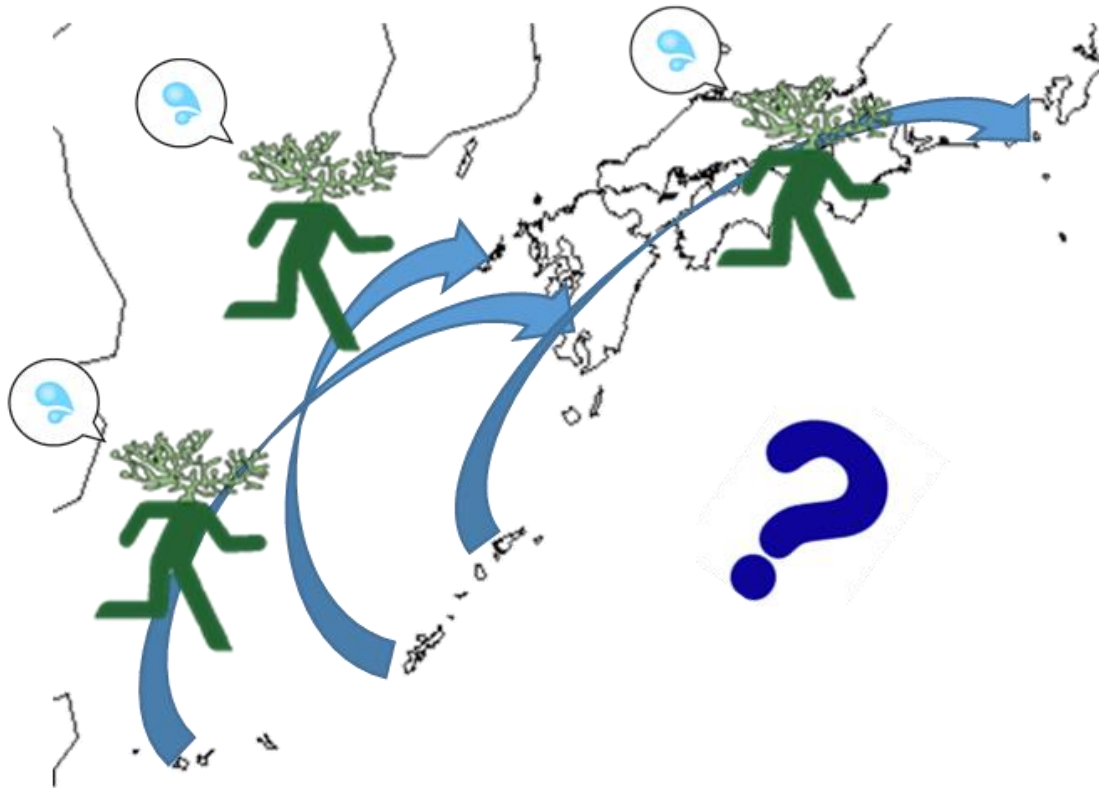
Distribution of coral *Acropora hyacinthus* 2016



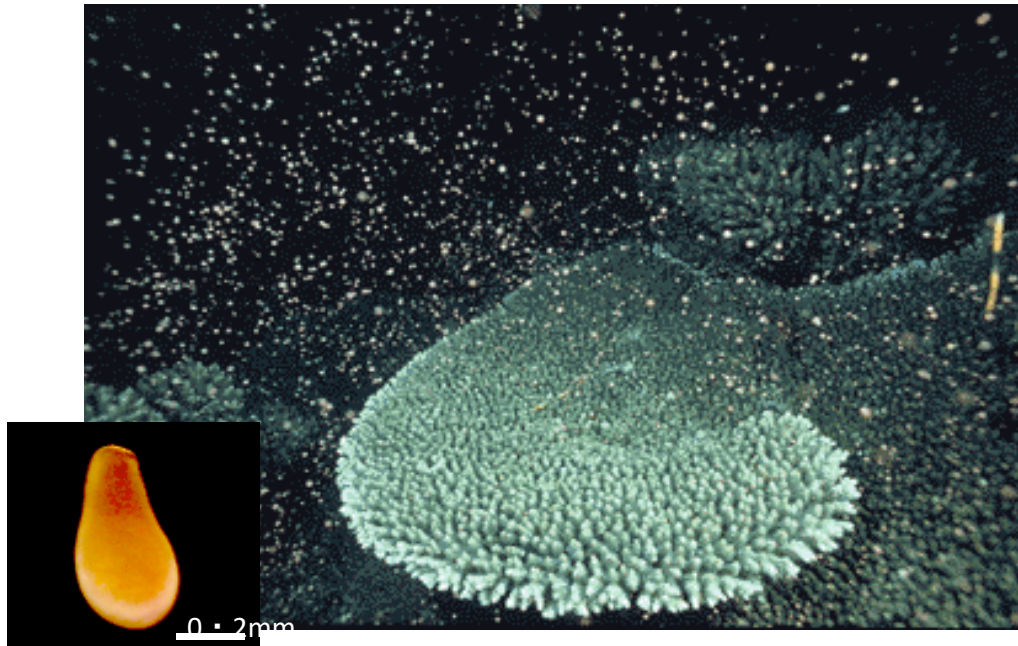
Some coral species are migrating and fleeing north

Yamano et al. 2011, Nakabayashi et al. 2017

Temperate region can be used as a refugia ? !

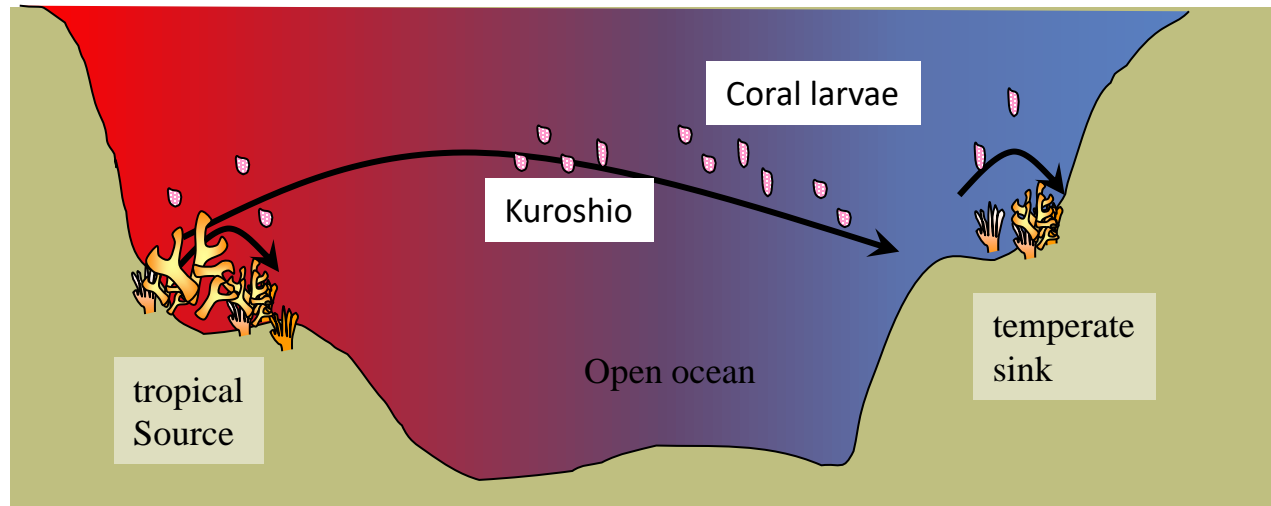


How do corals migrate to north?
=via larval dispersal



Mass coral spawning and larvae

Connectivity via larval dispersal is very important for coral conservation

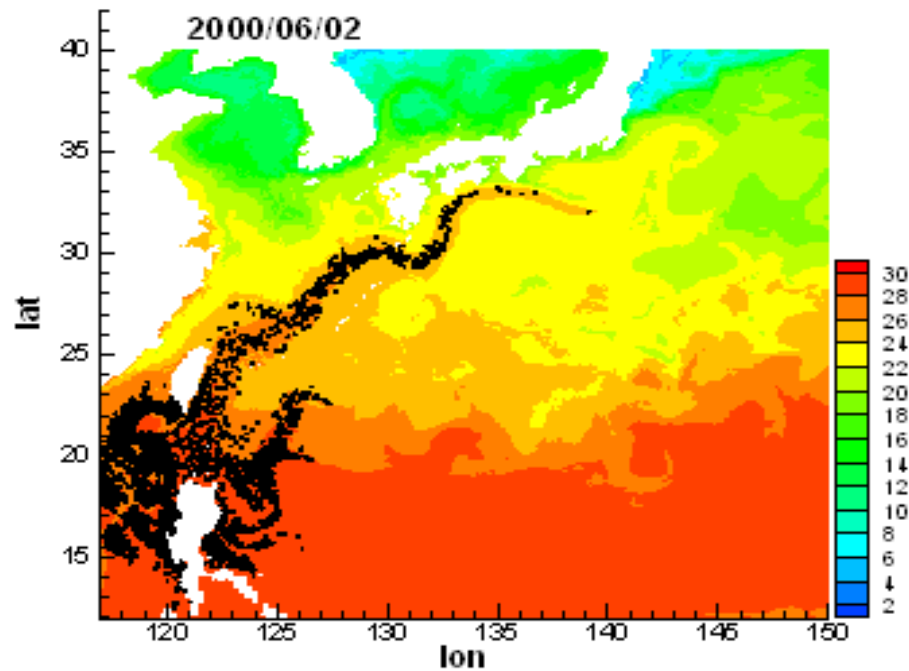


Purpose of the study

Review relative important marine region
considering

Ocean Current ▪ Genetic diversity ▪
Changes of coral area

Oceanographic larval dispersal simulation 27 years data

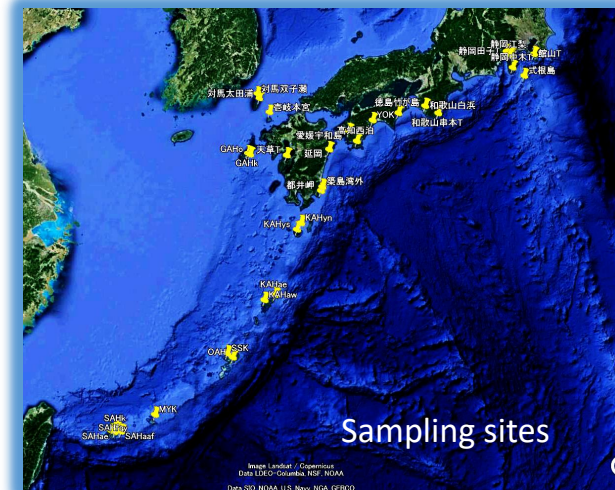


Assess larval dispersal patterns

Oceanographic larval dispersal simulations



Collected 4 coral genus from 32 sites in total 4000 samples
Population genetic analysis revealed number of cryptic species ▪
genetic diversity ▪ unique alleles



Happy student before the survey



After the survey



ZZZ....

Oceanographic larval dispersal simulations

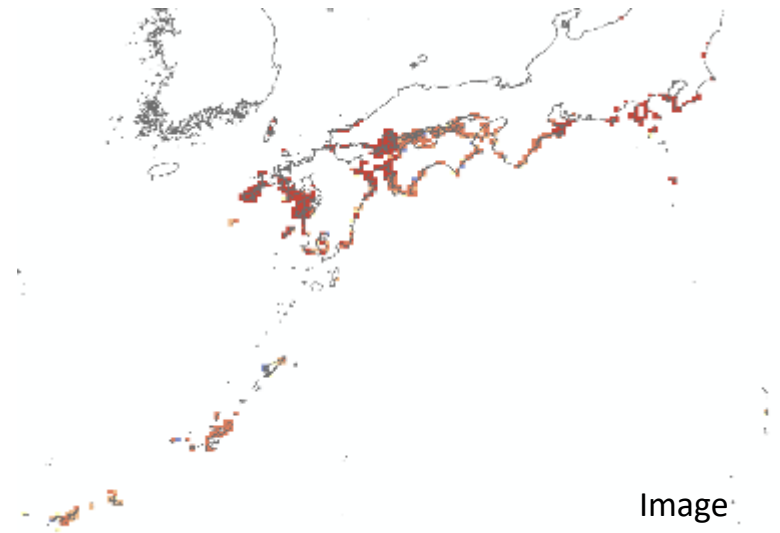


Collected 4 coral genus from 32 sites in total 4000 samples

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genetic diversity ▪ unique alleles



**Predict coral area using statistical
species distribution model**



Oceanographic larval dispersal simulations



Collected 4 coral genus from 32 sites in total 4000 samples
Population genetic analysis revealed number of cryptic species ▪
genetic diversity ▪ unique alleles



**Predict coral area using statistical
species distribution model**

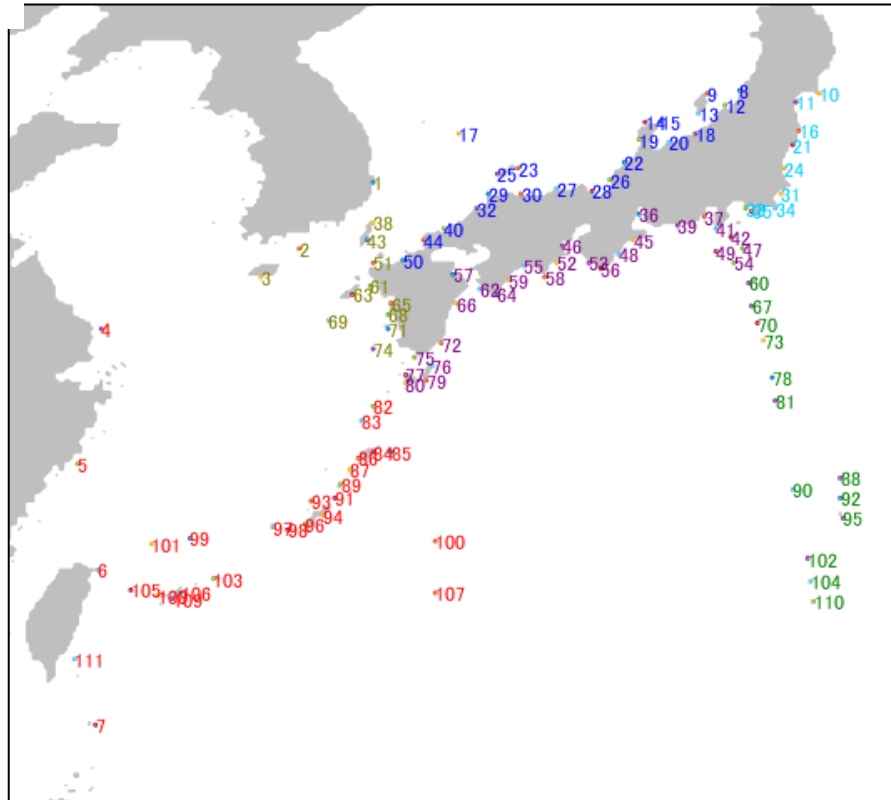


Estimate relative importance of each area

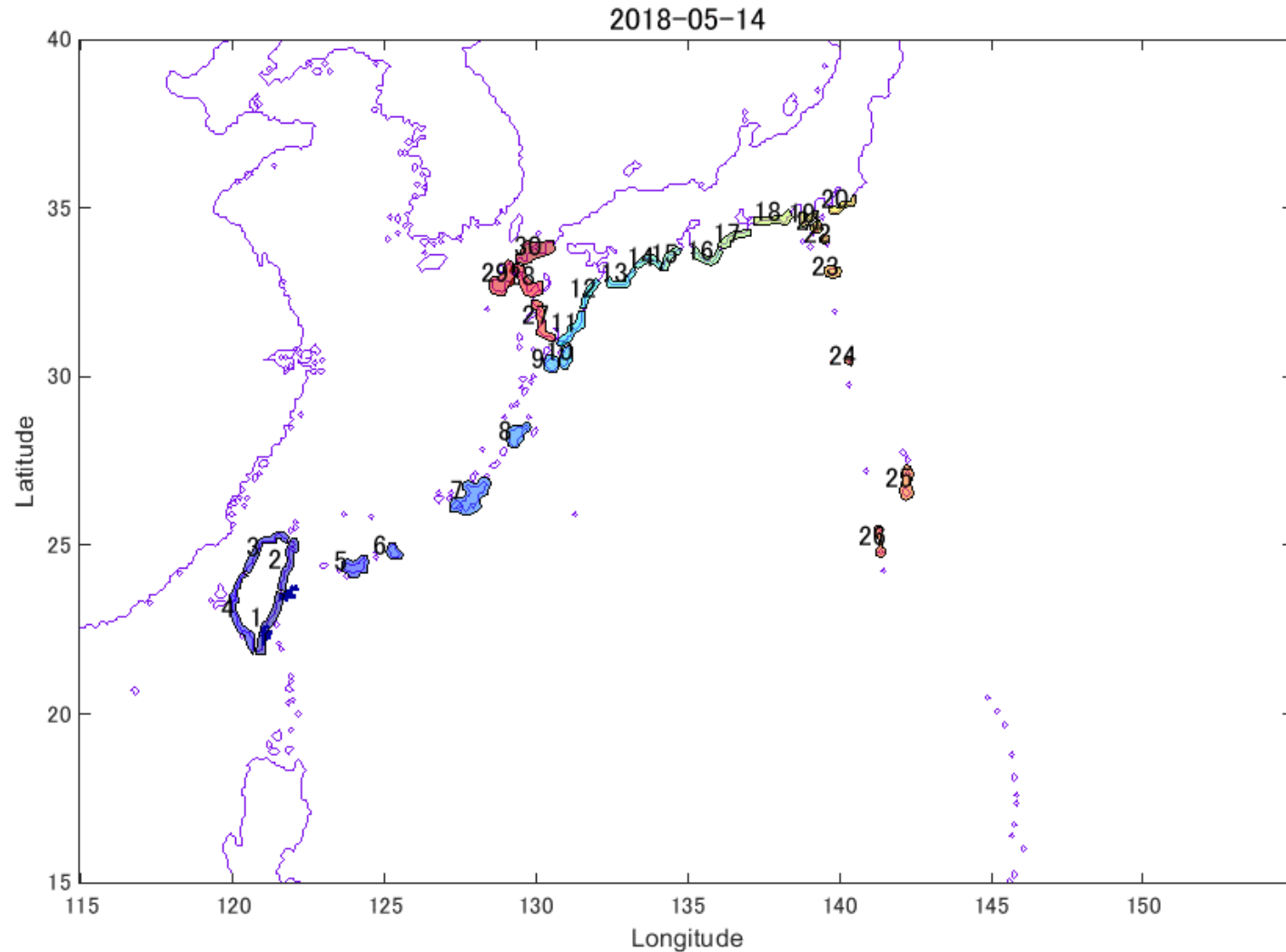


Oceanographic model(111 sites 27 years) Estimate larval connectivity

?

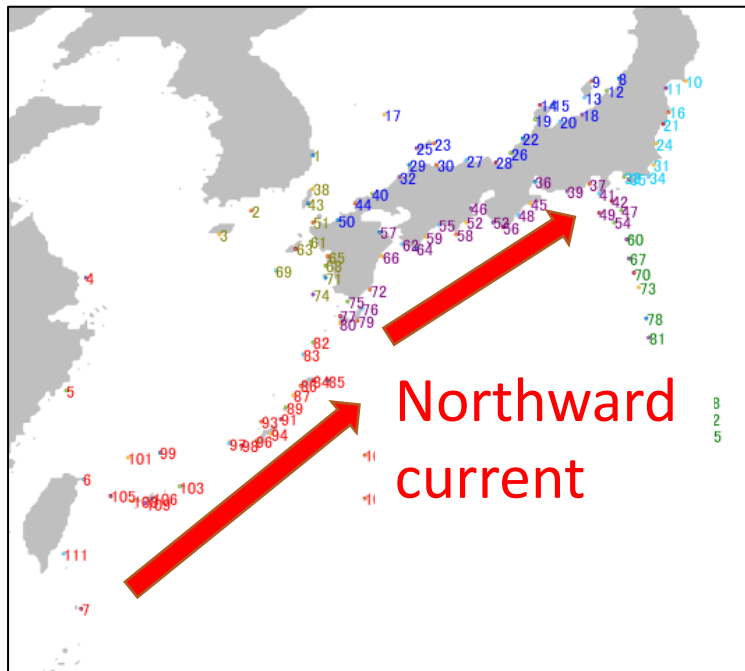


Larval dispersal simulation over 26 years

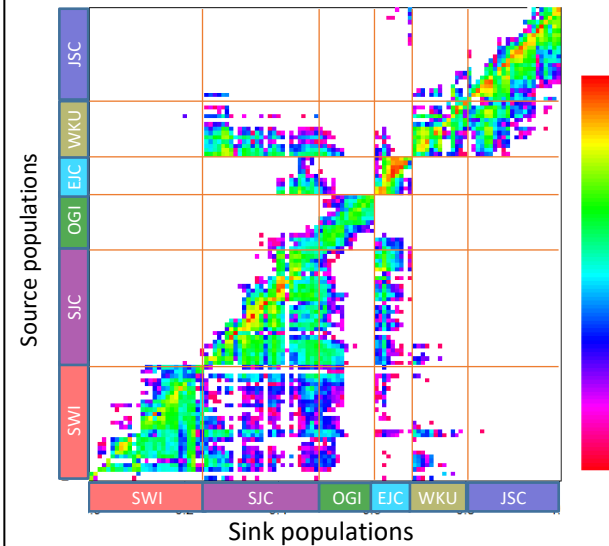


Overall larval dispersal along Kuroshio current

Movement of simulated larvae



Northward Dispersal

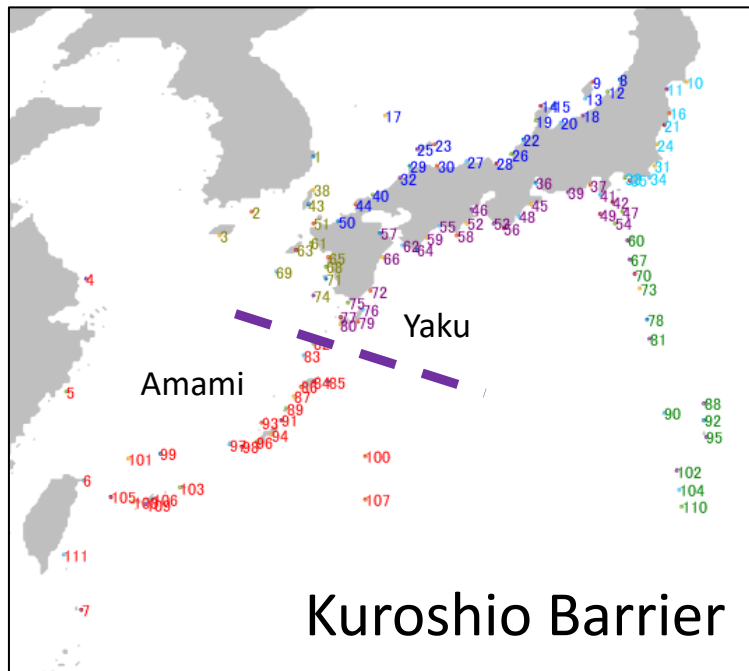


Connectivity among 111 sites

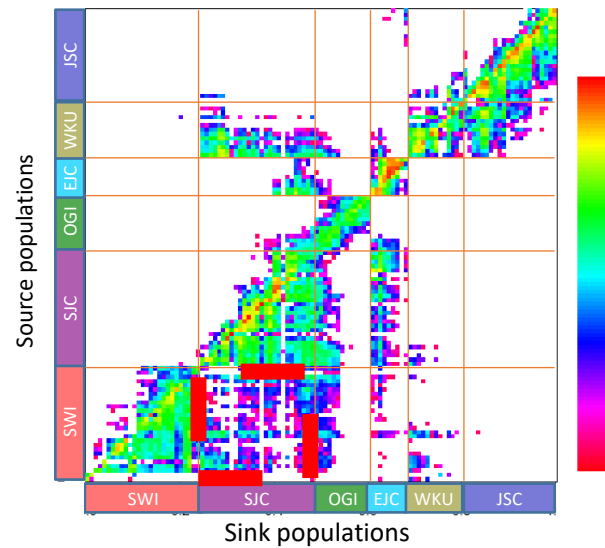
Nakabayashi (2019) Sci Rep

Larval dispersal is rather disconnected between Amami and Yaku

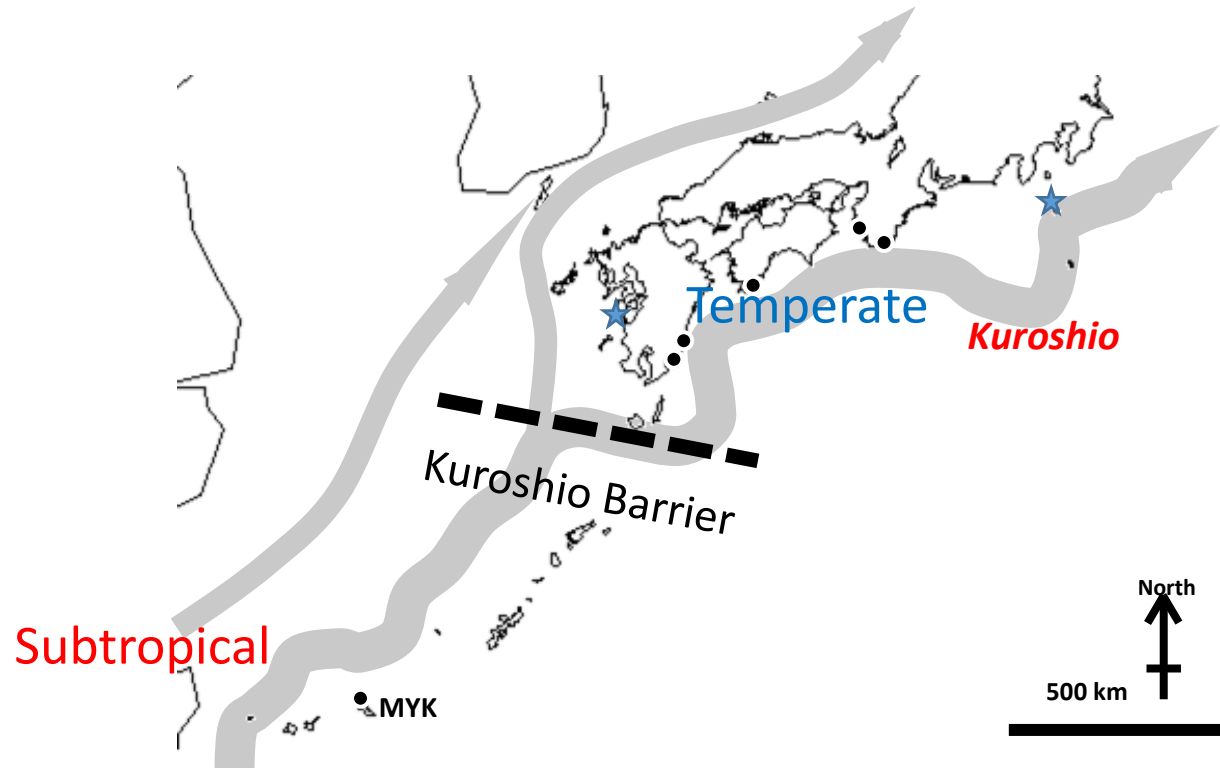
Larvae are released from 111 sites



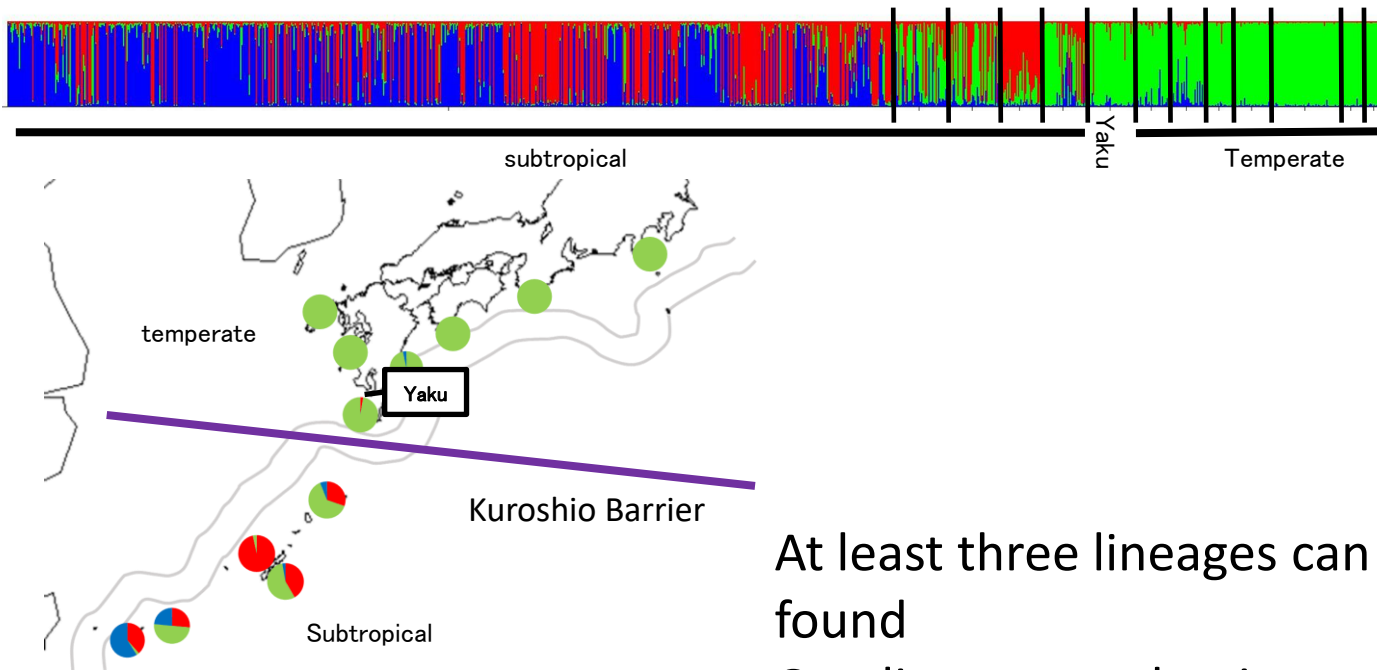
Connectivity matrix



Larval dispersal from tropical to subtropical within a generation is limited than expected



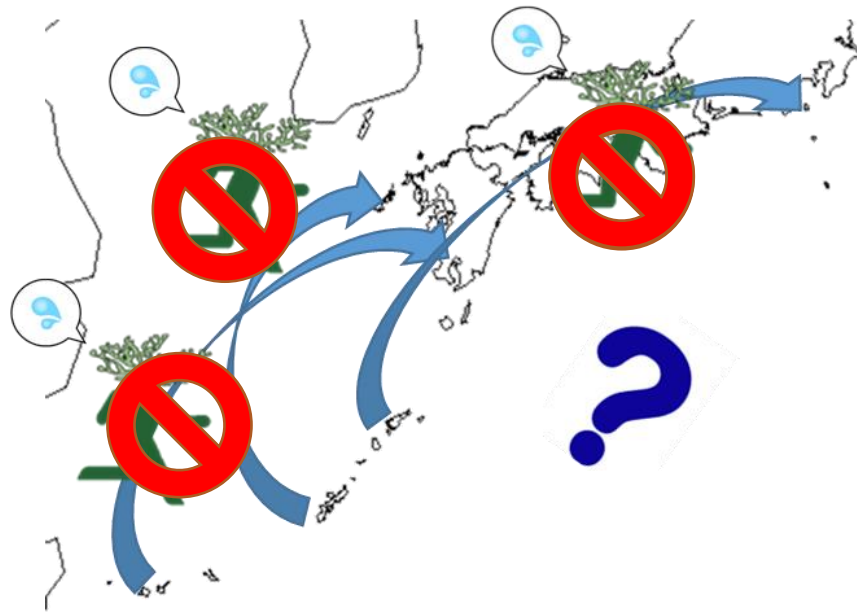
Cryptic species in *Acropora hyacinthus*



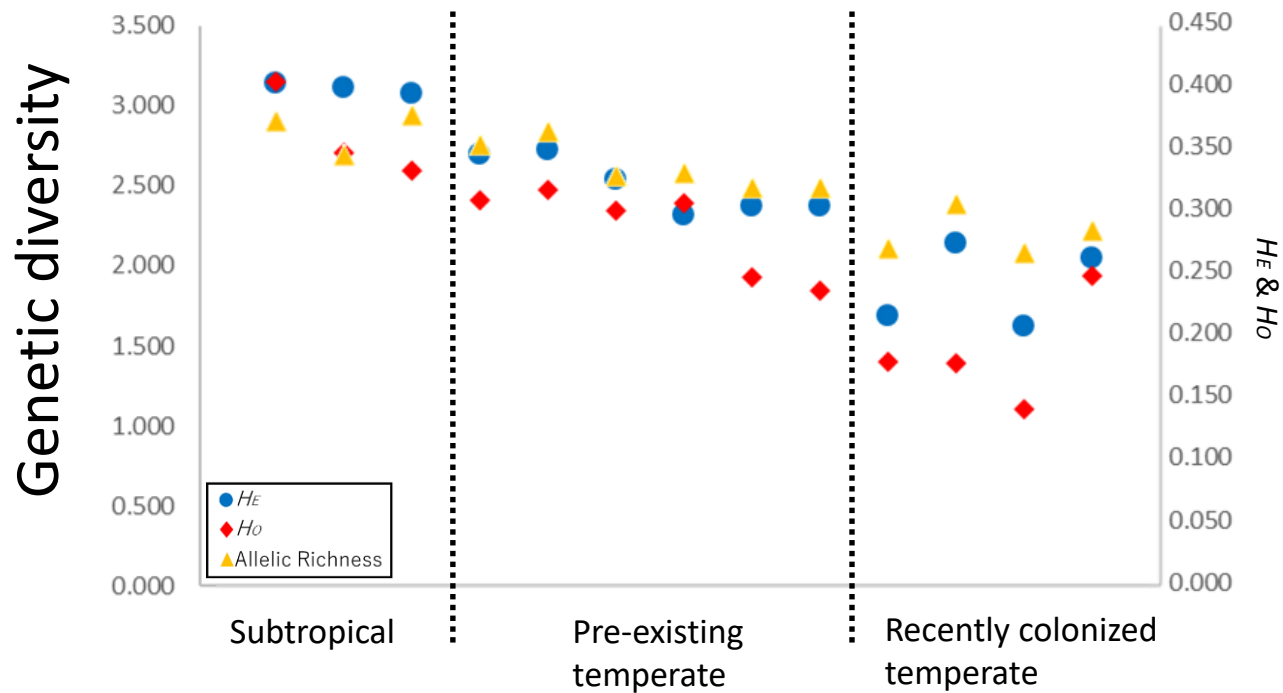
Nakabayashi et al (2019) Sci Rep

At least three lineages can be found
One lineage predominates in temperate area

Not all coral species or lineage
are escaping to north !



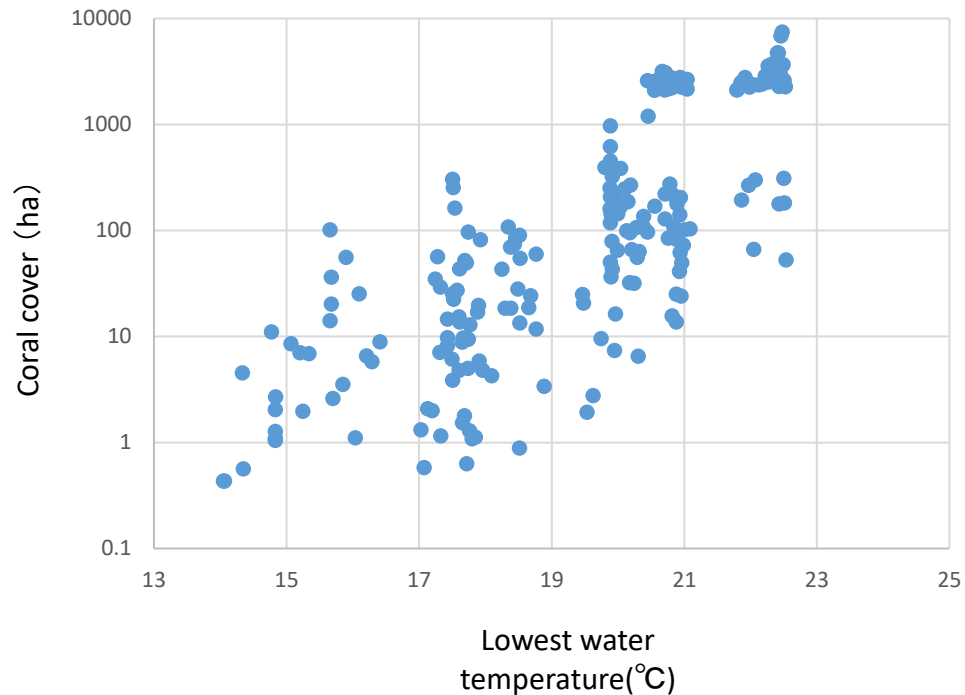
Genetic diversity decrease



South  North

Statistical species distribution model

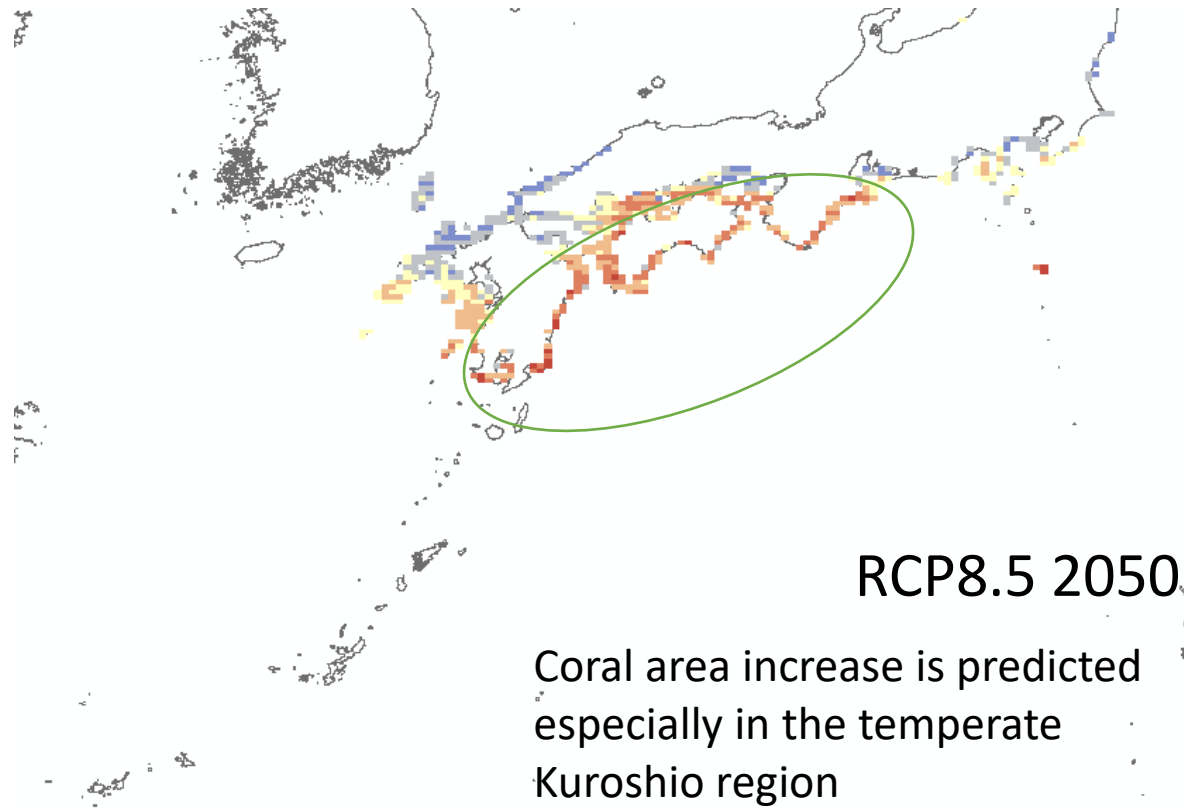
Change of coral cover (replaced from sea weed)



Environmental variables used to estimate statistical distribution model

Chlorophyll a、depth、length of coast line、turbidity、wave height、tidal current、lowest water temperature

Statistical modeling to predict coral cover increase in 2050





Ecologically or Biologically Significant Marine Areas (EBSAs)

Connectivity, genetic diversity, predicted coral cover will be included

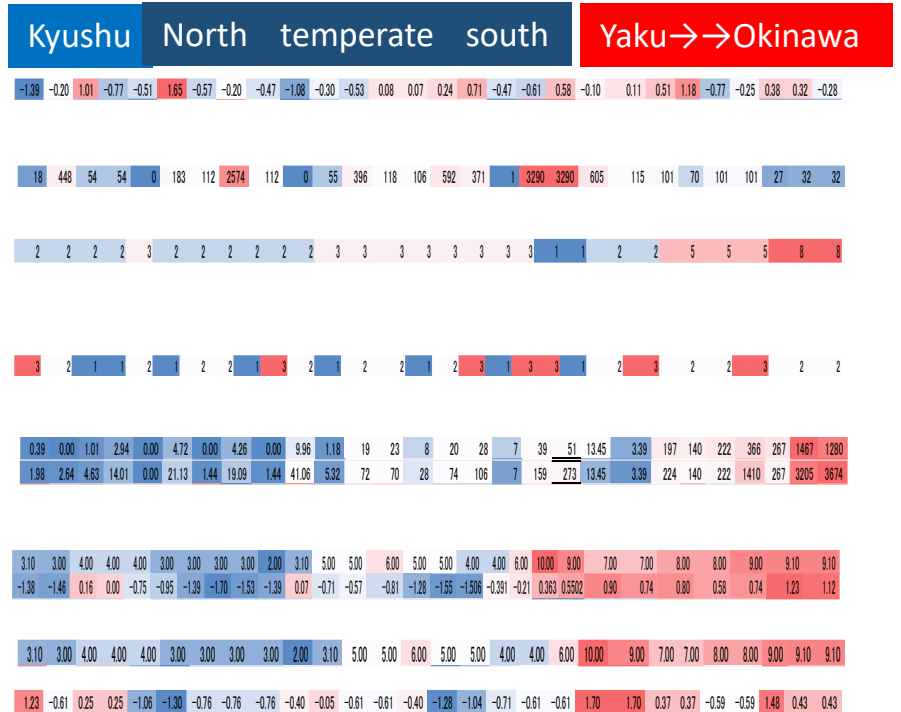
<https://www.env.go.jp/nature/biodic/kaiyo-hozen/ima.html>

CBD scientific criteria for ecologically or biologically significant areas (EBSAs) (annex I, decision IX/20)

1. Uniqueness or Rarity
2. Special importance for life history stages of species
3. Importance for threatened, endangered or declining species and/or habitats
4. Vulnerability, Fragility, Sensitivity, or Slow recovery
5. Biological Productivity
6. Biological Diversity
7. Naturalness

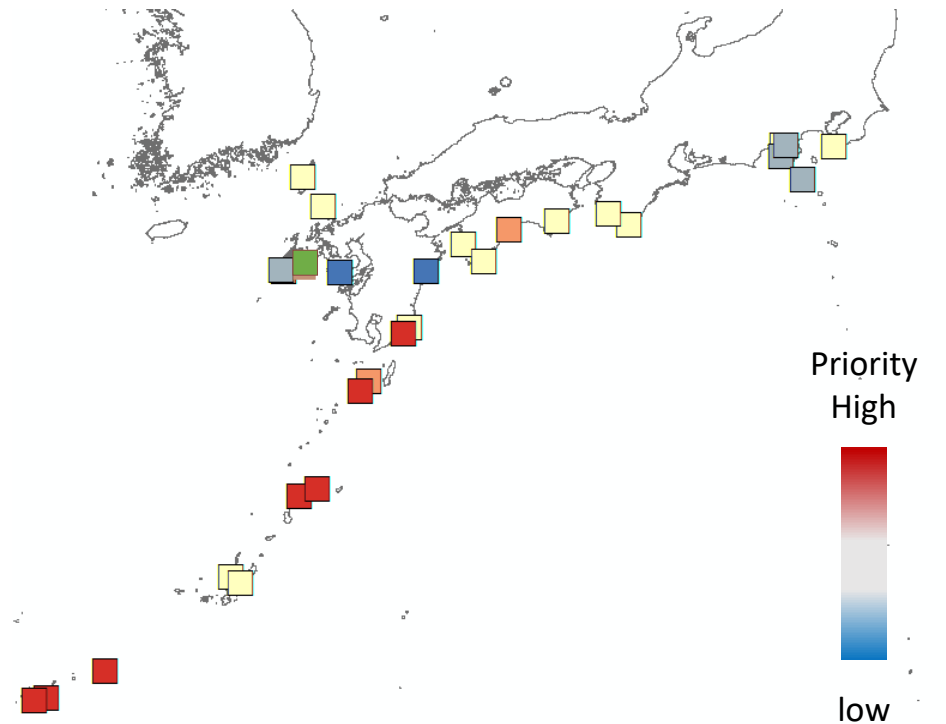
Applying connectivity, genetic diversity and species distribution to EBSA criteria

1. Uniqueness or Rarity: **number of private alleles**
2. Special importance for life history stages of species
Larval connectivity
3. Importance for threatened, endangered or declining species and/or habitats
4. Vulnerability, Fragility, Sensitivity, or Slow recovery
Clonal diversity
5. Biological Productivity: **coral area**
6. Biological Diversity: **genetic diversity**
7. Naturalness: **length of natural coast**



Priority Blue low—white: normal—red: high

Important area for conservation based on EBSA criteria



The result highlighted the relative importance of coral areas in the high Latitude for the first time (of course southern areas are important too)

Gap analysis

comparing the coral area with the current MPAs cover

▪ **High conservation priority but low MPAs coverage**

—Okinawa ▪ Nagasaki ▪ Kumamoto

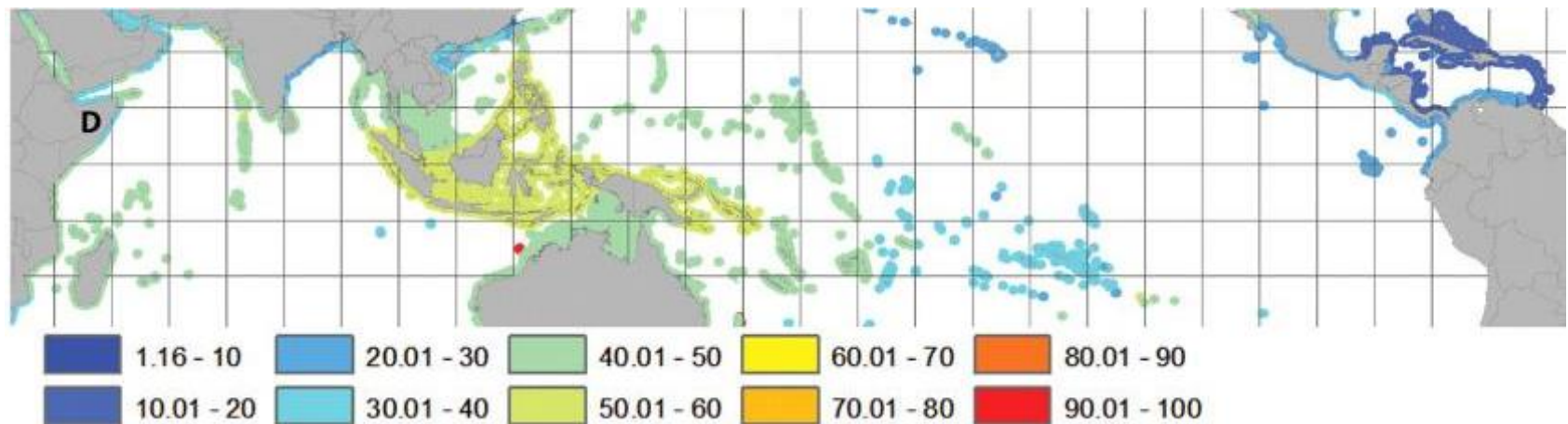
	MPA cover	Coral area	future Coral area
	0.00	0.2	3.5
	0.26	15.0	1.4
	0.00	0.1	3.5
	0.26	0.0	3.1
	0.07	1.3	1.4
	0.13	1.5	2.9
	0.17	1.5	2.0
Nagasaki	0.16	0.4	4.2
Kumamoto	0.11	1.7	3.3
	0.83	2.0	3.4
	0.19	4.7	1.8
	0.27	82.0	1.0
Okinawa	0.04	1798.5	0.0

The results was highly evaluated by
The Ministry of the Environment Japan



環境省
Ministry of the Environment

One-Third of Reef-building corals face elevated extinction risk! But we do not even know 'coral species boundaries'



Percentage of threatened or endangered species in a space (10 km²)

Carpernter et al. (2008)Science

One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts

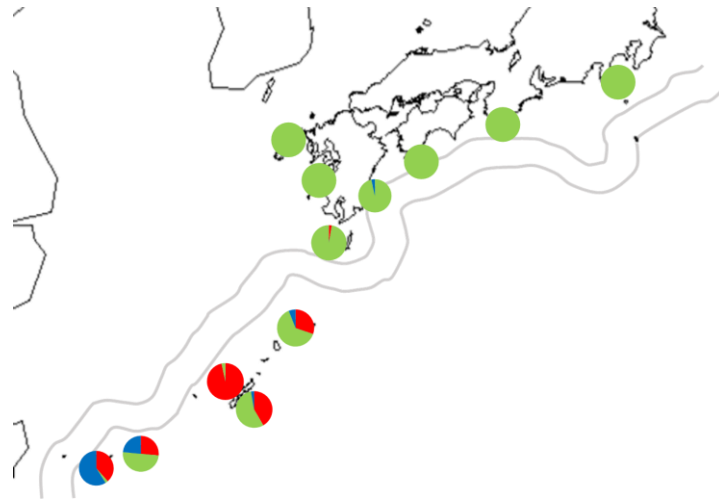
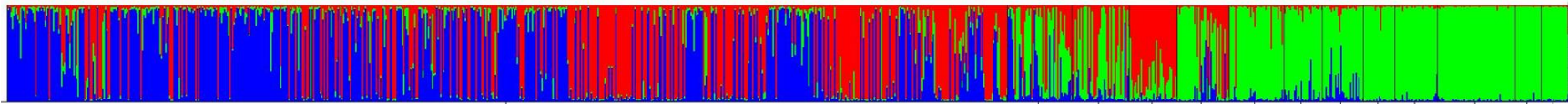
Kent E. Carpenter,^{1,*} Muhammad Abay,² Greta Aeby,³ Richard B. Aronson,⁴ Stuart Banks,⁵ Andrew Bruckner,⁶ Angel Chiriboga,⁷ Jorge Cortés,⁸ Charles Delbeek,⁹ Lyndon DeVantier,¹⁰ Graham J. Edgar,^{11,12} Alasdair J. Edwards,¹³ Douglas Fenner,¹⁴ Héctor M. Guzmán,¹⁵ Bert W. Hoeksma,¹⁶ Gregor Hodgson,¹⁷ Oluf Johan,¹⁸ Wilfredo Y. Licuanan,¹⁹ Suzanne B. Livingstone,²⁰ Edward R. Lovett,²¹ Jennifer A. Moore,²² David O. Obura,²³ Domingo Ochavillo,²⁴ Beth A. Palidoro,²⁵ William F. Precht,²⁶ Miledel C. Quiblan,²⁷ Clarissa Reboton,²⁸ Zoe T. Richards,²⁹ Alex D. Rogers,³⁰ Jonnell Sanciangco,³¹ Anne Sheppard,³² Charles Sheppard,³³ Jennifer Smith,³⁴ Simon Stuart,³⁵ Emre Turak,³⁶ John E. N. Veron,³⁷ Carden Wallace,³⁸ Ernesto Weil,³⁹ Elizabeth Wood⁴⁰

The conservation status of 845 zooecanthellate reef-building coral species was assessed by using International Union for Conservation of Nature Red List Criteria. Of the 704 species that could be assigned conservation status, 32.8% are in categories with elevated risk of extinction. Declines in abundance are associated with bleaching and diseases driven by elevated sea surface temperatures, with extinction risk further exacerbated by local-scale anthropogenic disturbances. The proportion of corals threatened with extinction has increased dramatically in recent decades and exceeds that of most terrestrial groups. The Caribbean has the largest proportion of corals in high extinction risk categories, whereas the Coral Triangle (western Pacific) has the highest proportion of species in all categories of elevated extinction risk. Our results emphasize the widespread plight of coral reefs and the urgent need to enact conservation measures.

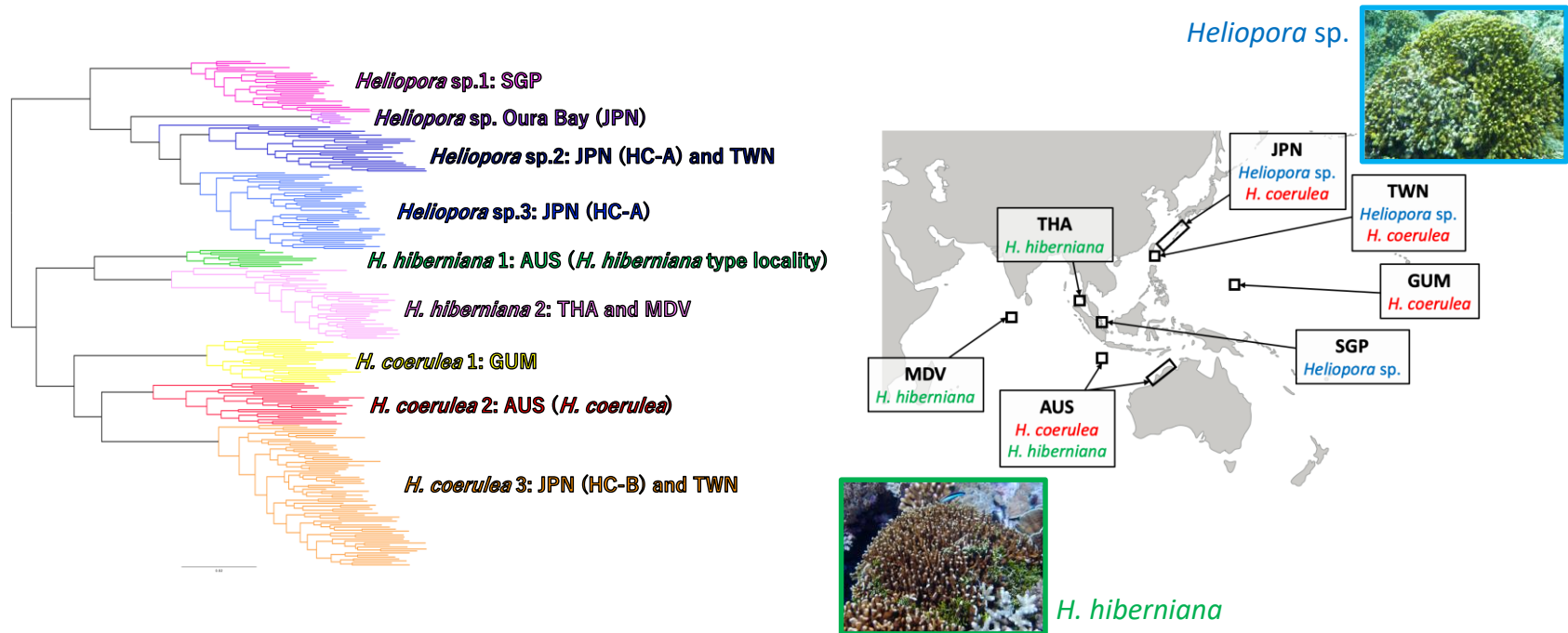
ion concentrations and the ability of corals to build skeletons (4). Local threats include human disturbances such as increased coastal development, sedimentation resulting from poor land-use and watershed management, sewage discharges, nutrient loading and eutrophication from agrochemicals, coral mining, and overfishing (1, 2, 5–9). Local anthropogenic impacts reduce the resilience of corals to withstand global threats, resulting in a global deterioration of reef structure and ability of these ecosystems to sustain their characteristic complex ecological interactions (1–3, 5–9).

In view of this ecosystem-level decline, we used International Union for Conservation of Nature (IUCN) Red List Categories and Criteria to determine the extinction risk of reef-building coral species. These criteria have been widely used and rely primarily on population size reduction and geographic range information to classify, in an objective framework, the extinction risk of a broad range of species (10). Categories range from Least Concern, with very little probability of extinction, to high risk, Critically Endangered (Table 1). The threatened categories (Vulnerable, Endangered, and Critically Endangered) are intended to serve as one means of setting priority measures for biodiversity conservation.

So many hidden coral species!
Limitation of biodiversity assessment base on gross
morphology of corals

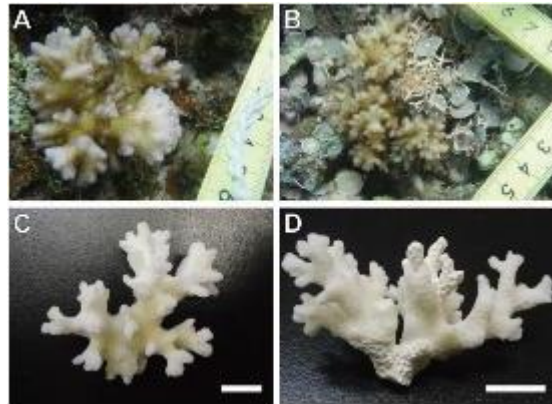


Population genomic analysis revealed at least 9 hidden lineages (possibly different species) in the Indo-Pacific

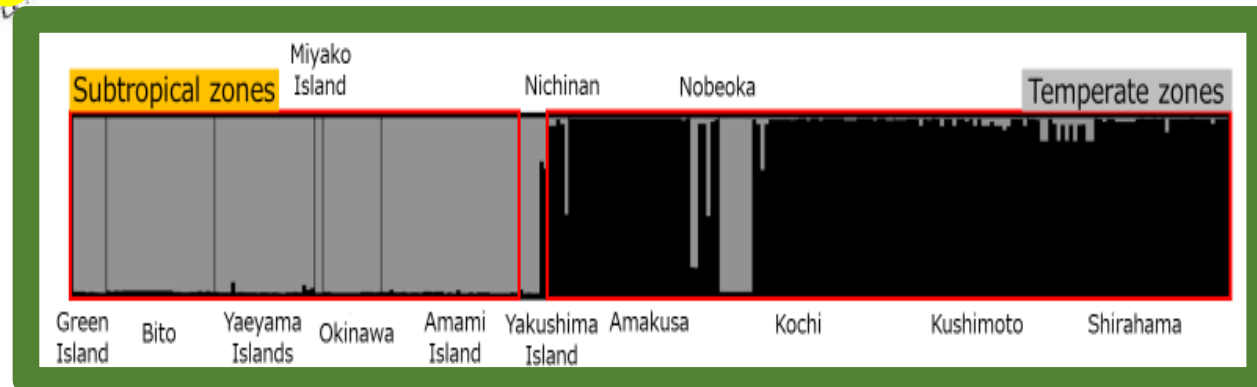
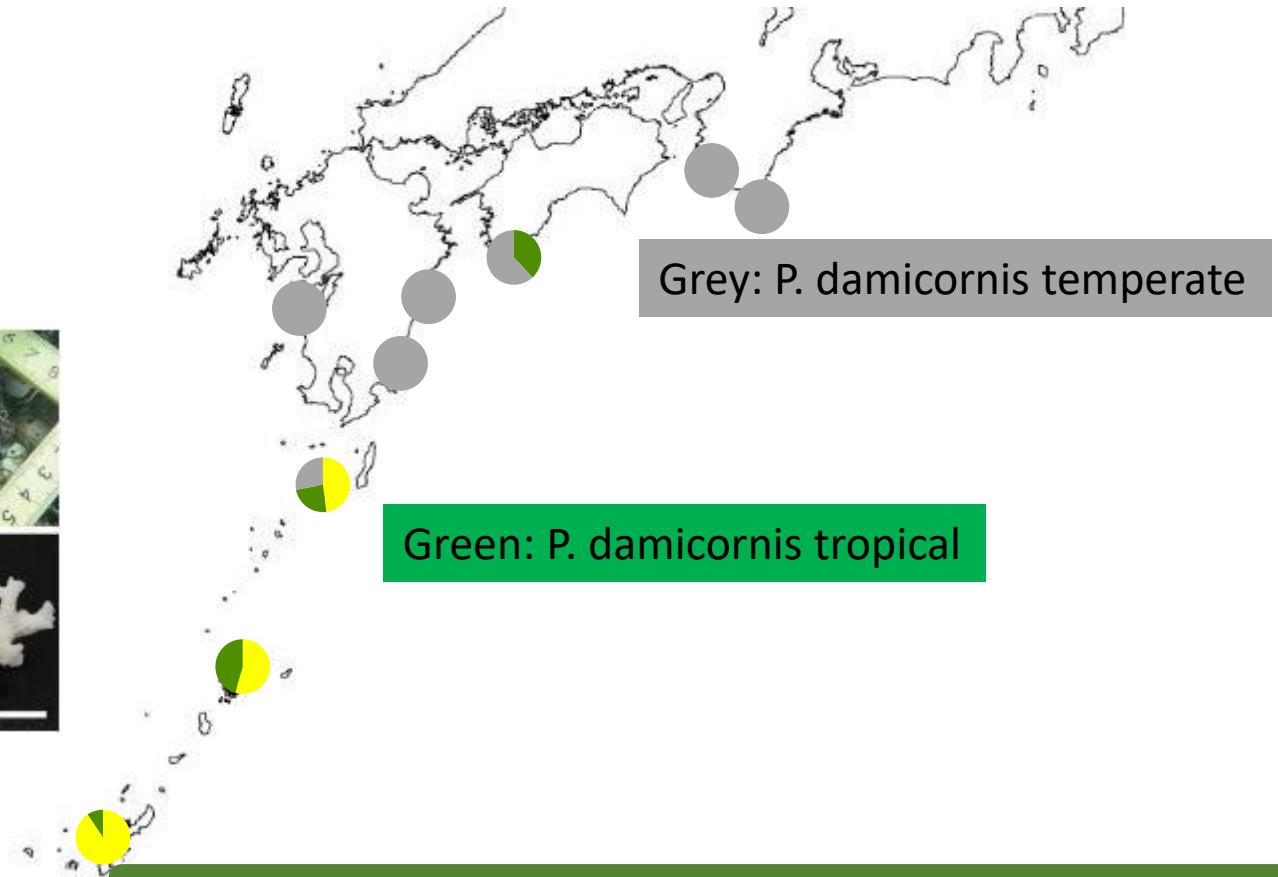


The blue coral (*Heliopora coerulea*) long thought to be one order, one family, one genus, and one species actually contained nine different lineages.
(Physiologically and ecologically different)

Pocillopora damicornis and *P. acuta*



Yellow: *P. acuta*

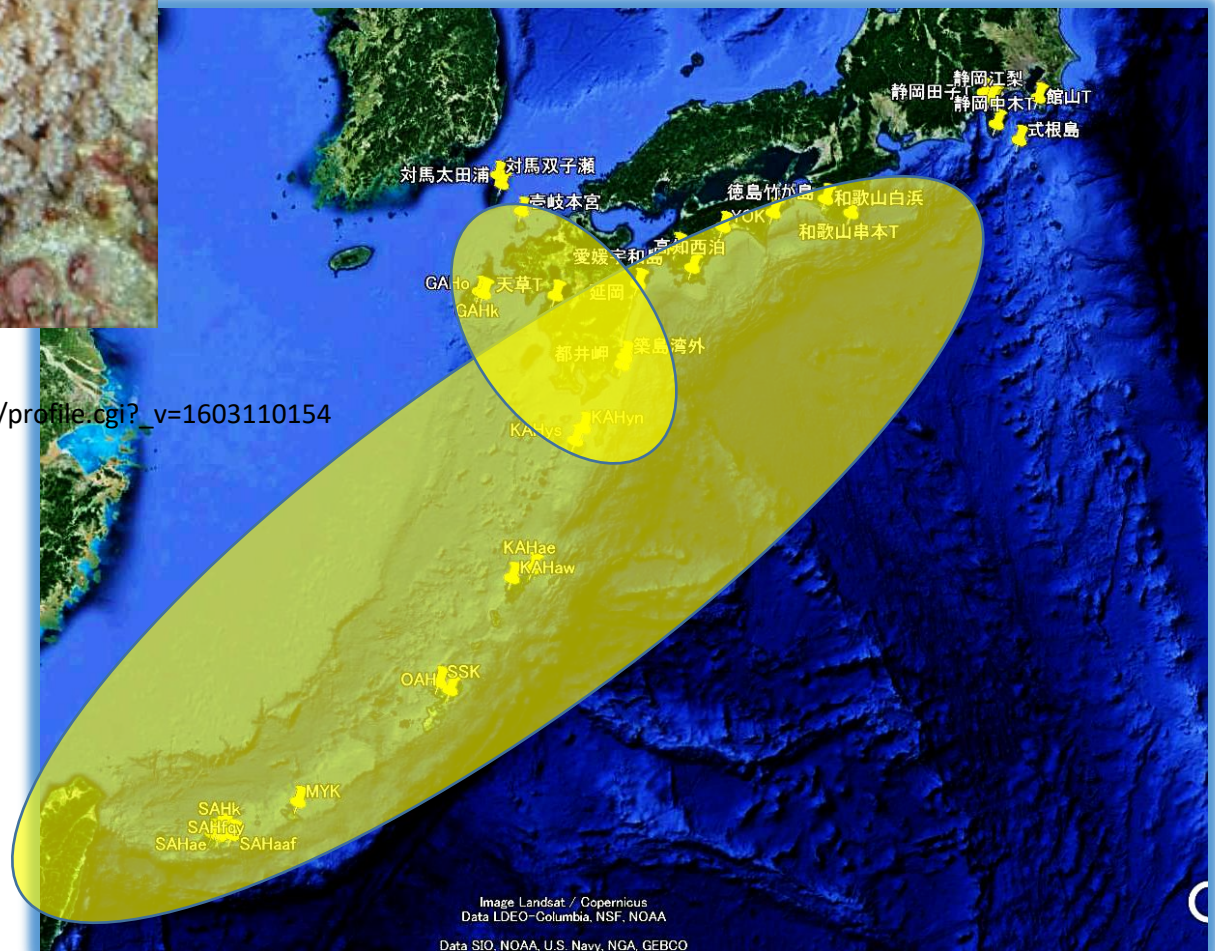


Goniopora djiboutiensis and *G.lobata*

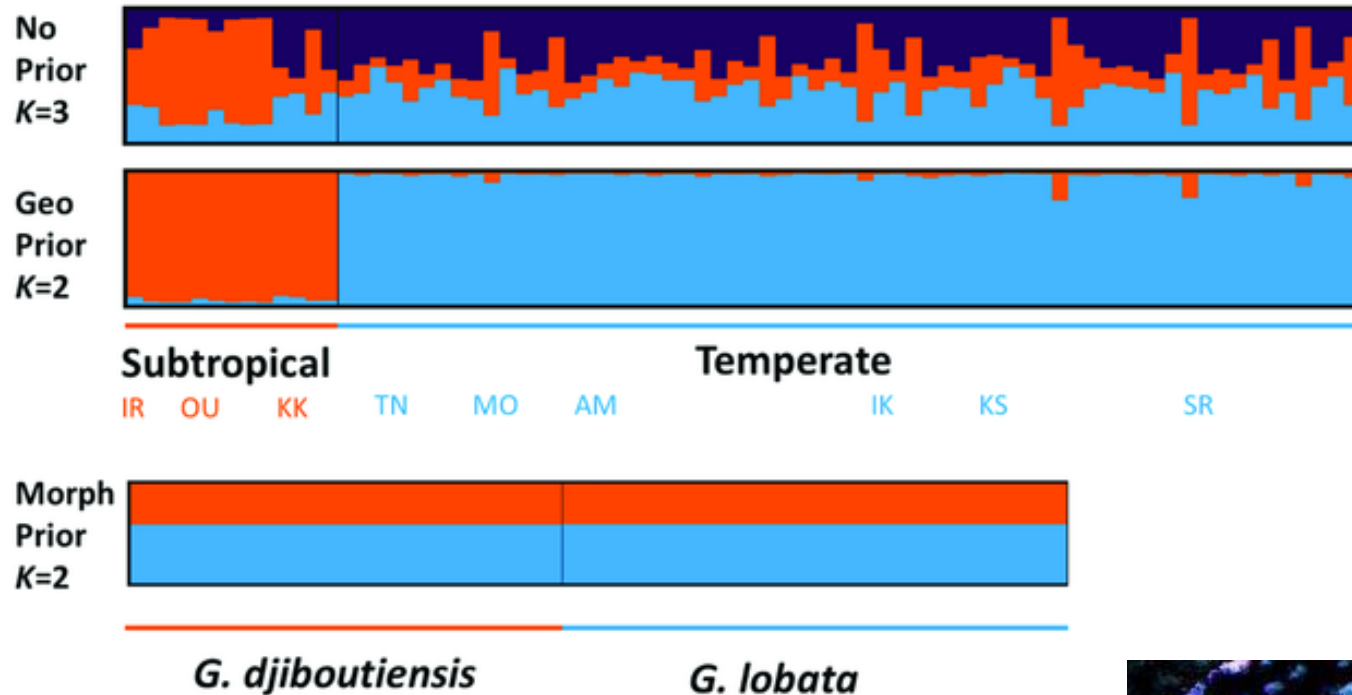


Photo by Keiichi Nomura
https://www.nies.go.jp/tanegashima/sango_db/profile.cgi?_v=1603110154&tpl=view2

No official record of northward migration



In *Goniopora* spp, regardless of morphological species, genetic break is observed between temperate and subtropical regions



If local adaptation occurs in each marine region, there is a possibility that the population originally located in the north could be threatened by migration load.

Many invisible coral conservation units should be clarified for conservation of coral diversity

→now we are creating genome-wide SNPs database

There is still little data on the genetic diversity of marine organisms, and we still don't know which 90% of the population should be conserved.

We need to accumulate such genetic diversity data in our database. In addition, genetic monitoring is important because climate change may cause invisible genotype shifts and migration pressures in the future.

If some of you can collaborate with us for making coral genetic database, please let me know!