International Workshop - Session 2

Coral reefs in a changing world - Climate change and land-based pollution issues and conservation strategies

Coral reefs in a changing world

-Climate change and land-based pollution issues and conservation strategies

*Hiroya YAMANO [1)]

1) Center for Environmental Biology and Ecosystem Studies, NIES, Japan
*Corresponding author (hyamano@nies.go.jp)

Keywords: Global warming; Ocean acidification; Land-based pollution, Marine protected area

Tropical and subtropical islands are associated with coral reefs, which provide ecosystem services, including fisheries, tourism and coastal protection. This is especially true to reef islands that are composed fully of reef-derived materials. Both global-scale (climate change) and local-scale (land-based pollution) have been causing significant change on coral reefs.

Japan provides an ideal setting to examine these changes, because it covers a wide latitudinal range, stretching from subtropical to temperate areas, and latitudinal limits of coral reefs and coral distributions are observed around the Japanese islands (Yamano et al., 2012). Seas around Japan showed significant sea surface temperature (SST) rises in winter (January–March) (1.1°C–1.6°C) (after Japan Meteorological Agency), which is critical for corals to survive at the latitudinal limits of their distribution. This means that Japan provides a unique opportunity for examining baselines of species range shifts and/or expansions due to climatic warming over a large spatial scale. In addition, some islands have significant amount of sediment discharge through rivers as a result of extensive land development. So land-based pollution issues can be examined. In this presentation, I present recent progress on environmental change and coral reefs achieved by NIES.

In the Ryukyu Islands, located in the southern part of Japan, mass coral bleaching occurred in 1998. After that, other bleaching events occurred in 2001 and 2007. These events were driven by anomalously high SSTs in summer, which suggests that rising SSTs would cause higher frequency of bleaching. Aerial photographs taken before and after the 2007 bleaching event revealed 2/3 of corals were lost in the Sekisei Lagoon. On the other hand, range expansion of corals was observed in the mainland Japan and Kyushu and Shikoku. We collected records of coral species occurrence from eight temperate regions of Japan along a latitudinal gradient, where past coral occurrence records were available in the form of literature and specimens since the 1930s. After careful examination of the species distribution, we detected four species showed range expansions, with speeds of up to 14km/year (Yamano et al., 2011).

Future projection of coral reef status would require consideration of another important issue, ocean acidification, caused by dissolved CO_2 in seawater. Higher concentration of dissolved CO_2 cause reduction in aragonite (one of the forms of $CaCO_3$ that construct coral skeletons) saturation state (Ω_{arag}). We used climate model outputs for SST and Ω_{arag} and present-day their threshold values for coral distribution to project future coral habitats. Without consideration of coral adaptation and/or acclimation, in high CO_2 emission (SRES 2A) scenario, coral habitats will be lost in the 2070s because of higher SST in the south and lowered Ω_{arag} in the north (Yara et al., 2012). On the other hand, lowered CO_2 emission (SRES 1B) scenario, coral could survive around the Ryukyu Islands even in the 2090s. This strongly suggests the importance of reducing CO_2 emission for conservation of corals (Yara et al., in preparation).

Extensive land development and modification after the reversion of Okinawa to Japan in 1972 caused significant increase in sediment discharge, which is called "red-soil discharge (RSD)" because the color of the sediment shows red because of weathering. RSD caused significant decline in both river and coastal ecosystems. In response to these environmental issues related to RSD, Okinawa Prefecture established The Okinawa Prefecture Red Soil Erosion Prevention Ordinance in 1994, and it was enforced by October 1995. As a result, RSD from construction sites was restricted successfully. However, strict regulation for RSD from farmlands was not applied, and present-day significant source for RSD is sugarcane farmland. Geochemical analysis of coral annual bands indicated land modification caused increase in sediment discharge into coastal waters and caused decreases in coral calcification (Inoue et al., 2014; Sowa et al., 2014).

Land-based pollution appears to affect recovery of corals after bleaching. A 15-year monitoring results showed no recovery of corals at sites affected by RSD, while a site without RSD showed recovery of coral cover (Hongo and Yamano, 2013). This means that reducing other stressors such as land-based pollution would be an effective way to enhance resilience of corals to bleaching, in addition to reducing CO_2 emission. Because sediments are derived from farmlands, integrated framework to consider land-sea connections and regional economy, i.e., setting biodiversity conservation targets, identifying sediment source areas by monitoring and modeling, and estimating costs for preventing sediment discharge from farmlands is needed, in order to prioritize the farmlands to conserve river and coastal ecosystems.

In the sea, marine protected areas (MPAs) are an effective tool for conserving coastal ecosystems. Identifying the candidate areas based on rigorous scientific knowledge is required, because MPAs in Japan have been designated based mainly on seascapes. Generating large-scale databases for species distribution and physical environments would contribute to set up new MPAs for conserving biodiversity (Yamakita et al., 2015). Further, because distributional ranges are shifting/expanding, marine protected areas that incorporate these shifts/expansions are required. Integration of climate model outputs and spatial planning would help identify the areas (Makino et al., 2014). A data-based, spatially-explicit, transdisciplinary approach is required for future conservation of coral reefs in a changing world.

References:

Hongo, C. and Yamano, H. (2013) Species-specific responses of corals to bleaching events on anthropogenically turbid reefs on Okinawa Island, Japan, over a 15-year period (1995-2009). PLoS One, 8, e60952.

Inoue, M., Ishikawa, D., Miyaji, T., Yamazaki, A., Suzuki, A., Yamano, H., Kawahata, H. and Watanabe, T. (2014) Evaluation of Mn and Fe in coral skeletons (*Porites* spp.) as proxy for sediment loading and reconstruction of fifty years of land use on Ishigaki Island, Japan. Coral Reefs, 33, 363-373.

Makino, A., Yamano, H., Beger, M., Klein, C.J., Yara, Y. and Possingham, H.P. (2014) Spatio-temporal marine conservation planning to support high-latitude coral range expansion under climate change. Divers. Dist., 20, 859-871.

Sowa, K., Watanabe, T., Kan, H. and Yamano, H. (2014) Influence of land development on the calcification of Holocene *Porites* coral at Nagura Bay, Ishigaki Island, Japan. PLoS One, 9, e88790.

Yamakita, T., Yamamoto, H., Nakaoka, M., Yamano, H., Fujikura, K., Hidaka, K., Hirota, Y., Ichikawa, T., Kakehi, S., Kameda, T., Kitajima, S., Kogure, K., Komatsu, T., Kumagai, N.H., Miyamoto, H., Miyashita, K., Morimoto, H., Nakajima, R., Nishida, S., Nishiuchi, K., Sakamoto, S., Sano, M., Sudo, K., Sugisaki, H., Tadokoro, K., Tanaka, K., Jintsu-Uchifune, Y., Watanabe, K., Watanabe, H., Yara, Y., Yotsukura, N., and Shirayama, Y. (2015) Identification of important marine areas around the Japanese Archipelago: Establishment of a protocol for evaluating a broad area using ecologically and biologically significant areas selection criteria. Mar. Policy, 51, 136-147.

Yamano, H., Sugihara, K. and Nomura, K. (2011) Rapid poleward range expansion of tropical reef corals in response to rising sea surface temperatures. Geophys. Res. Lett., 38, L04601.

Yamano, H., Sugihara, K., Watanabe, T., Shimamura, M. and Hyeong, K. (2012) Coral reefs at 34°N, Japan: Exploring the end of environmental gradients. Geology, 40, 835-838.

Yara, Y., Vogt, M., Fujii, M., Yamano, H., Hauri, C., Steinacher, M., Gruber, N. and Yamanaka, Y. (2012) Ocean acidification limits temperature-induced poleward expansion of coral habitats around Japan. Biogeosciences, 9, 4955-4968.

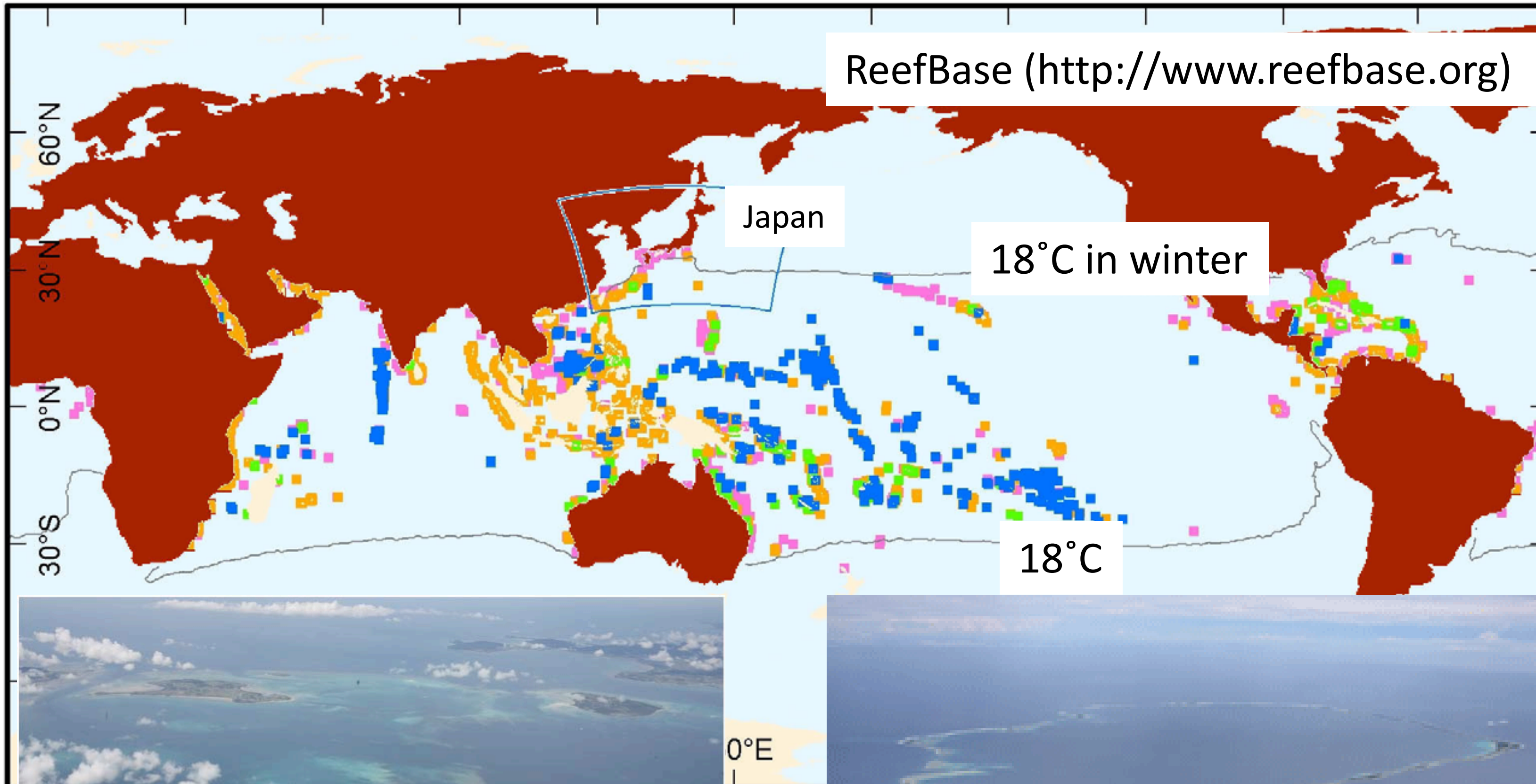
Coral reefs in a changing world -Climate change and land-based pollution issues and conservation strategies-

Hiroya Yamano
(National Institute for Environmental Studies)

Outline

- Coral reefs at risk
- Climate change and land-based pollution
- Framework for sustainable land and coastal ecosystems

Global distribution of coral reefs



Coral reefs are an essential component for tropical/subtropical coasts

Importance of coral reefs

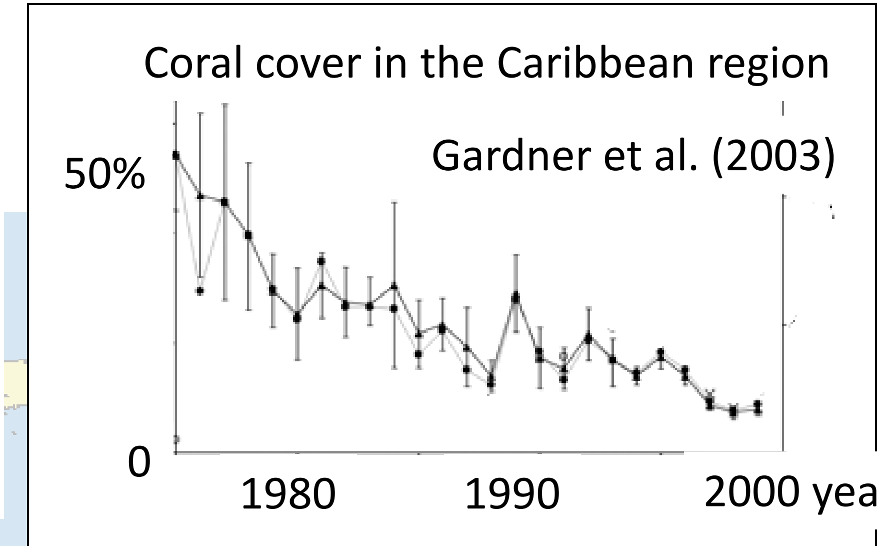
Photo: H. Kan

Photo: H. Kayanne

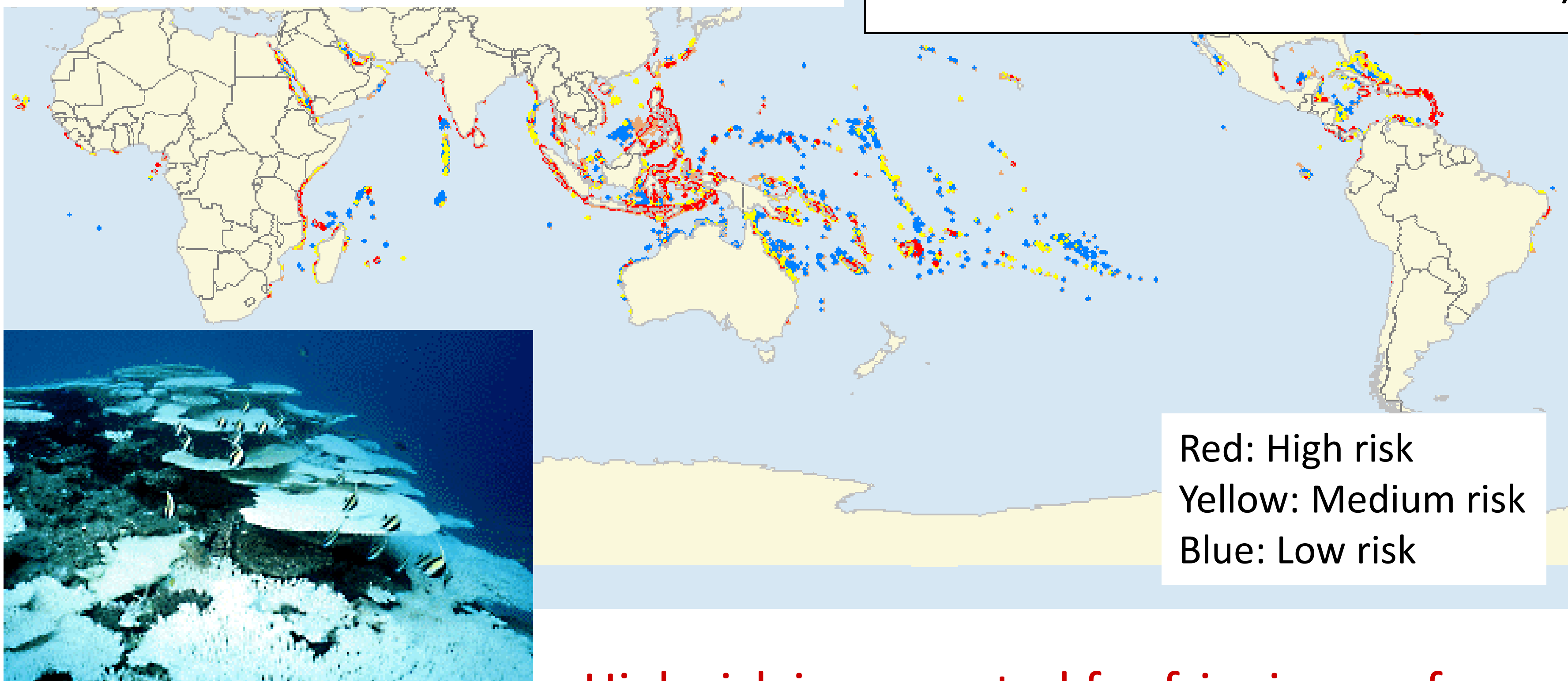
Biodiversity
Fisheries
Tourism
Natural breakwater
Island and beach maintenance

Estimated value for the ecosystem service
\$375,000,000,000/year
=\$6,075/ha/yr
(Wilkinson, 2002)

Recent decline of coral reefs



Sea surface temperature rise
Ocean acidification
Terrestrial input (sediment/nutrient discharge)
Overuse
Combined effect of global and regional stresses



“Reefs at Risk”
(http://www.reefbase.org)

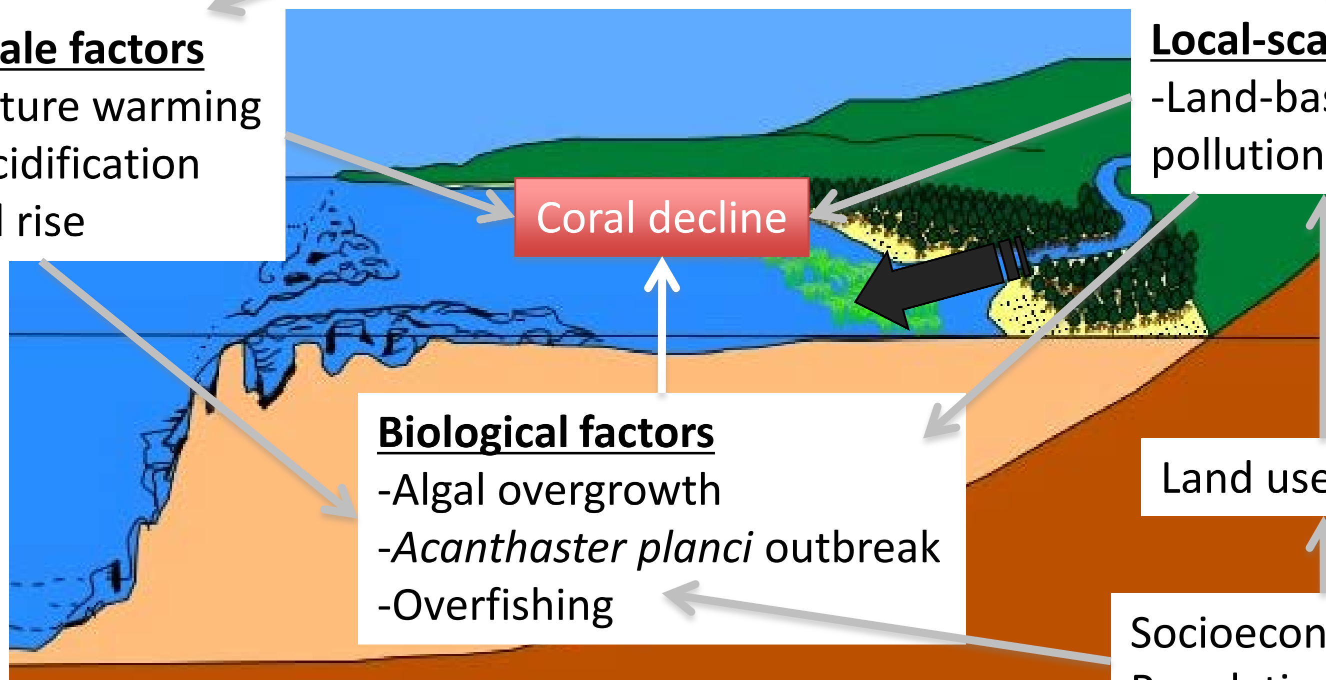
High risk is suggested for fringing reefs close to land

Multiple stressors on coral reefs

CO_2 emission → Climate change → Precipitation

Global-scale factors
- -Temperature warming
- -Ocean acidification
- -Sea-level rise

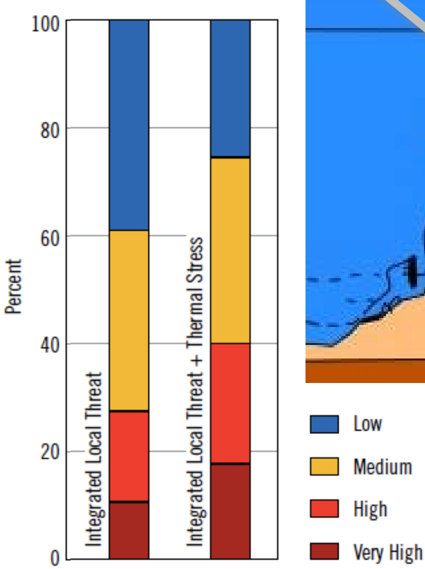
Local-scale factor
- -Land-based pollution



Biological factors
- -Algal overgrowth
- -*Acanthaster planci* outbreak
- -Overfishing

Land use change

Socioeconomic
Population increase



Local
60% at risk

Local + global
75% at risk

Source: Reefs at Risk revisited

Observation methods: Remote sensing
- -Satellite data
- -Aerial photographs
- -Surveillance camera
- -Boat-based video

\+ In situ species distribution data

Outline

- Coral reefs at risk
- Climate change and land-based pollution
- Framework for sustainable land and coastal ecosystems

Sea surface temperatures (SSTs) are rising

<u>SST warming in the last 50 yrs (Global)</u>

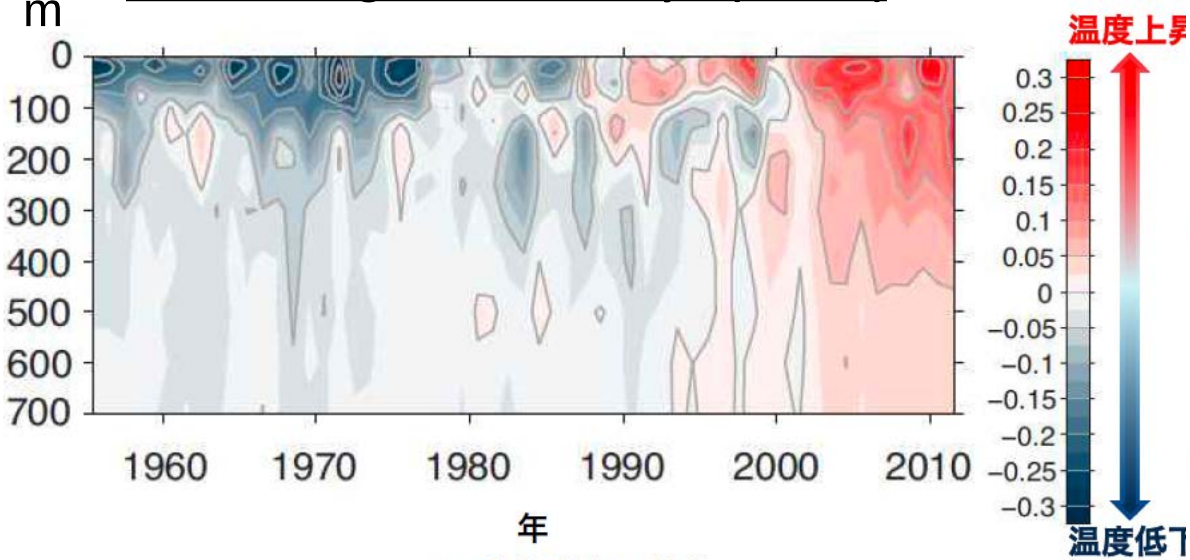
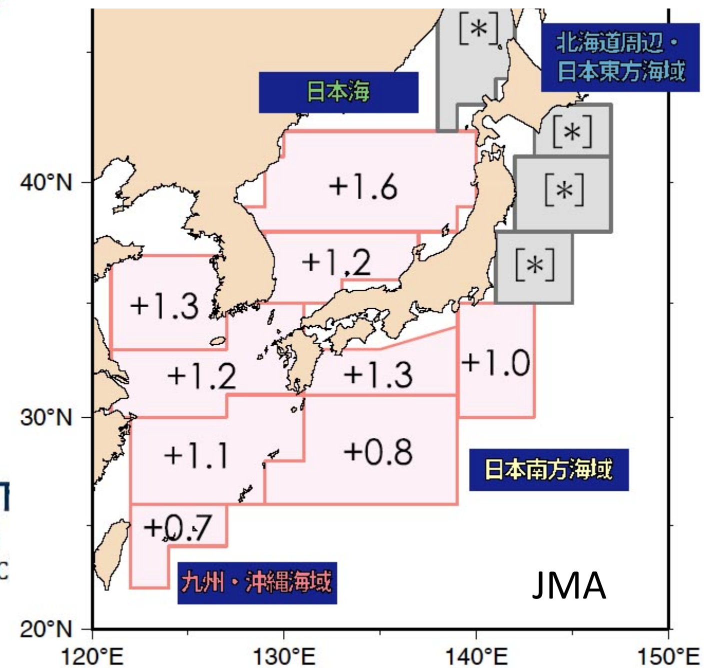


図. 全球平均海水温偏差
（1971年-2010年平均からの差）

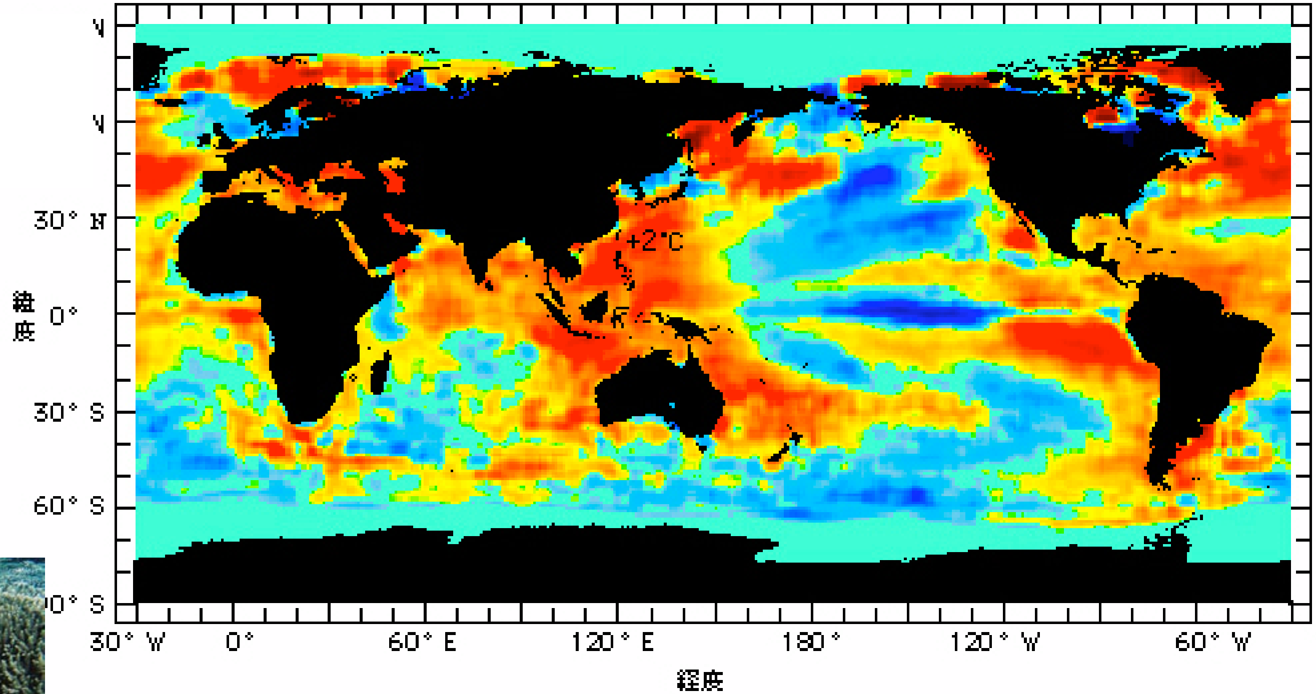
IPCC AR5

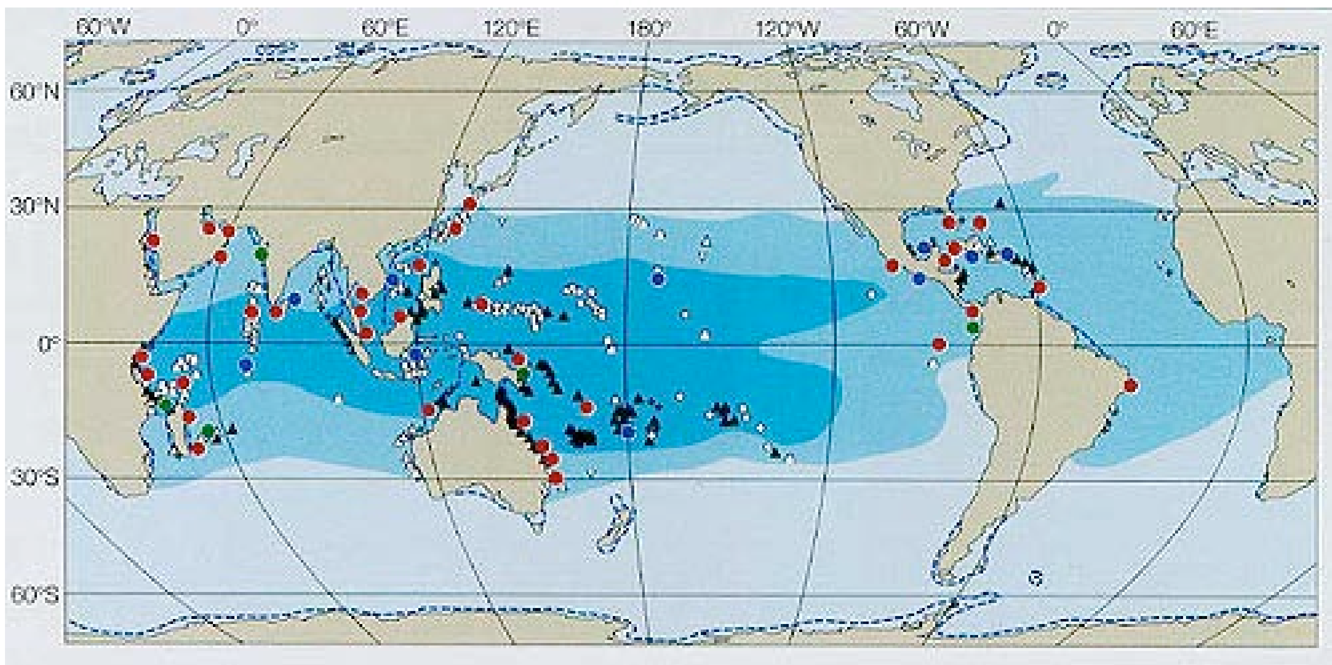
<u>SST warming in the last 100 yrs (around Japan)</u>



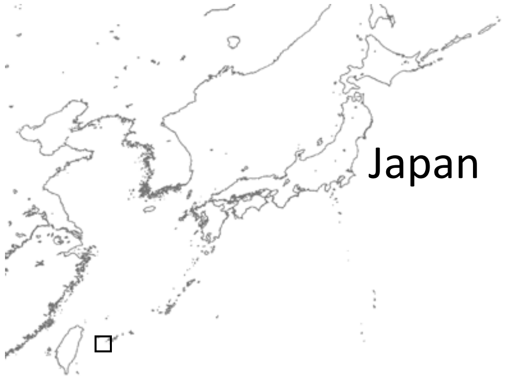
JMA

SST in 1998 and coral bleaching

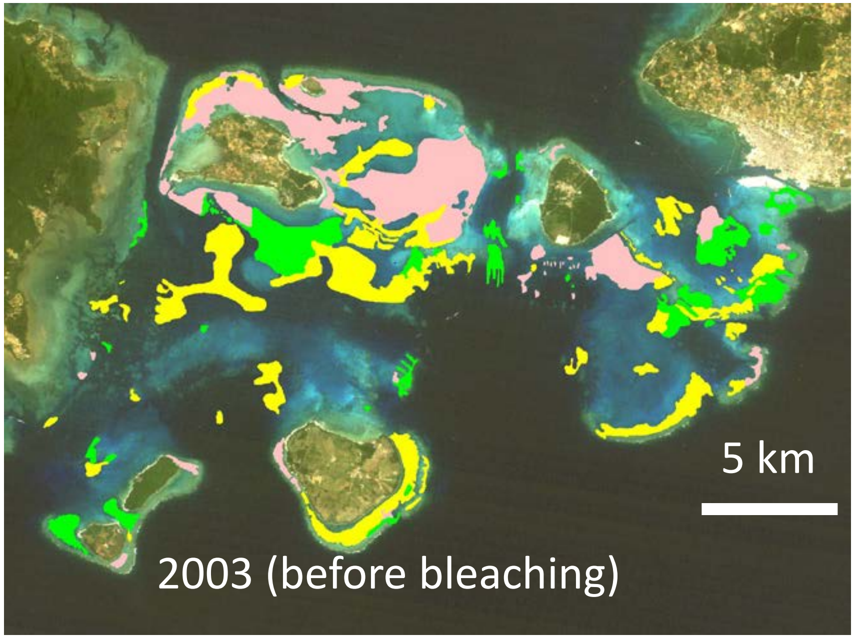


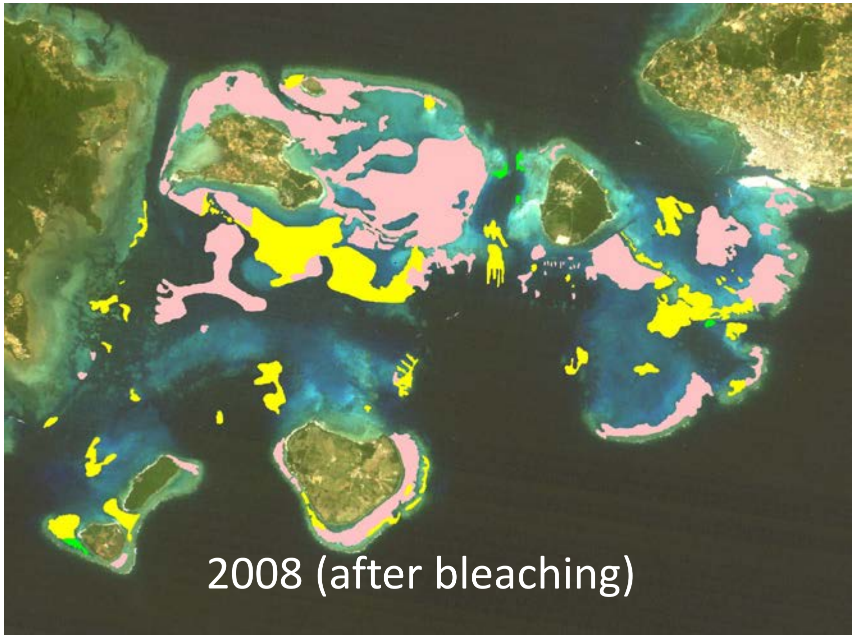


2007 coral bleaching in Japan



Live coral cover
Green : 50-100 %
Yellow : 5-50 %
Pink : <5 %





Source: Ministry of the Environment

naturenews

nature news home | news archive | specials | opinion | features | news blog

comments on this story

Stories by subject
- Ecology

Stories by keywords
- coral
- coral reefs
- climate change

This article elsewhere
- Blogs linking to this article
- Add to Connotea
- Add to Digg
- Add to Facebook
- Add to Newsvine
- Add to Del.icio.us
- Add to Twitter

Published online 21 January 2011 | Nature | doi:10.1038/news.2011.33

News

Coral marches to the poles

Reefs may simply move house when the oceans heat up.

Nicola Jones

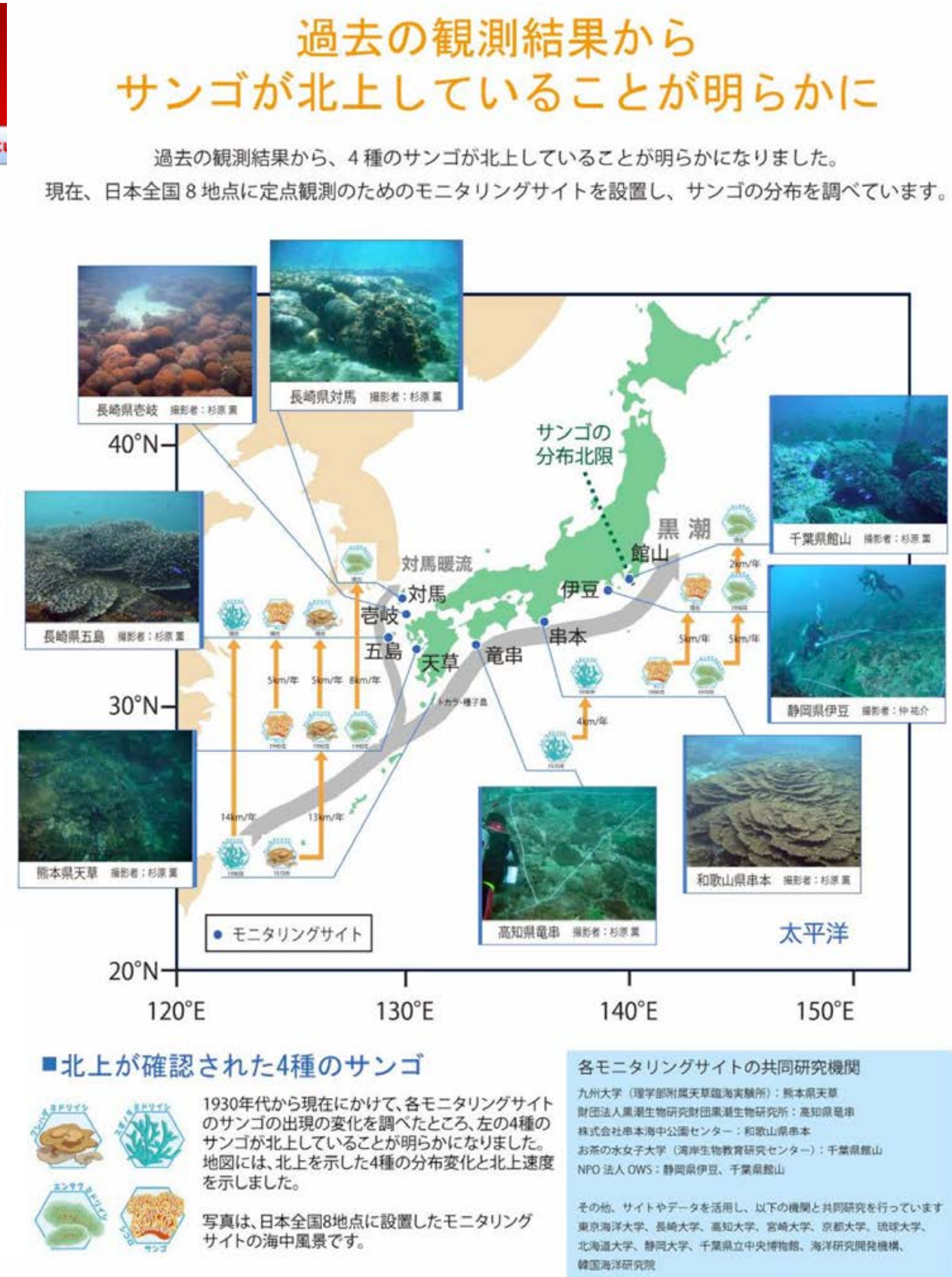
Corals around Japan are fleeing northwards, according to a new study. One type has been spotted 'sprinting' at 14 kilometres a year, thanks to a lift from ocean currents. That means ocean ecosystems could shift rapidly in the face of climate-change impacts such as warming seas, the authors say.

The corals found to have migrated north since 1930 were all classed as 'vulnerable' or 'near threatened'.

Aqua Image / Alamy

The study, due to be published in *Geophysical Research Letters*[1], is the first documentation of coral mass migration, but matches up with several other observations. As early as 2004 in Florida, for instance, staghorn and elkhorn corals were observed farther north than their usual ranges[2], and in Australia, reef-dwelling fish have been found farther south than before.

Hiroya Yamano of the Center for Global Environmental Research in



Range expansion of corals around Japanese temperate area due to SST warming

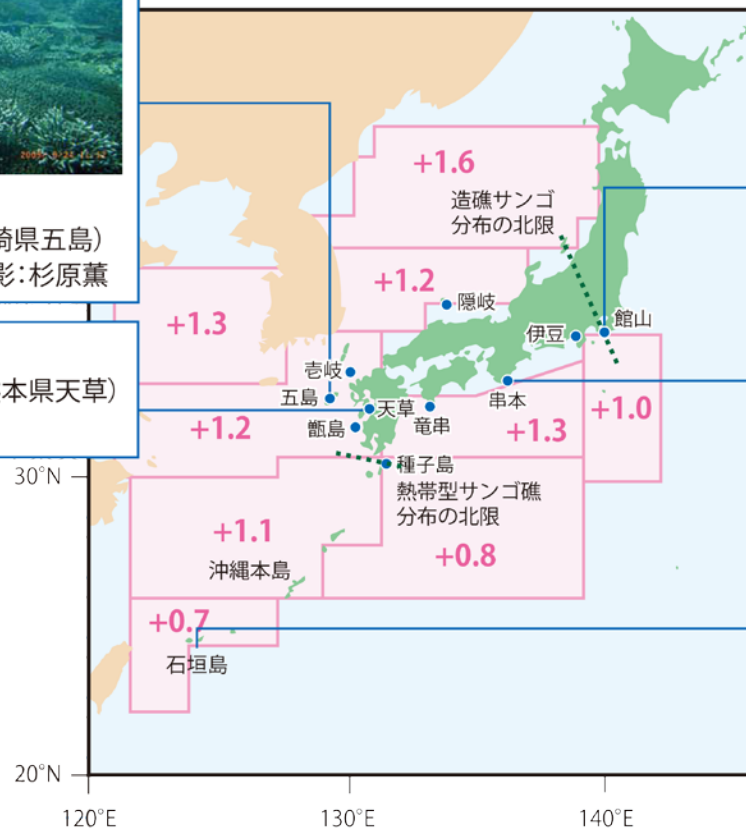
Maximum speed: 14km/yr

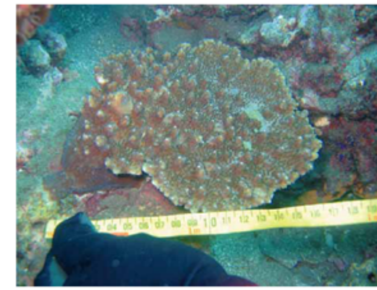
Yamano et al. (2011) *Geophysical Research Letters*

SST warming allows poleward range expansion (north) and bleaching (south) of corals in Japan

分布北上が確認された
クシハダミドリイシ(左)とスギノキミドリイシ(右) (長崎県五島)
撮影:杉原薫

分布拡大が確認された
エンタクミドリイシ (熊本県天草)
(野島・岡本, 2008)





分布北上が確認された
エンタクミドリイシ (千葉県館山)
撮影:萩原慎司

20種が新たに出現 (和歌山県串本)
(野村ほか, 2008)

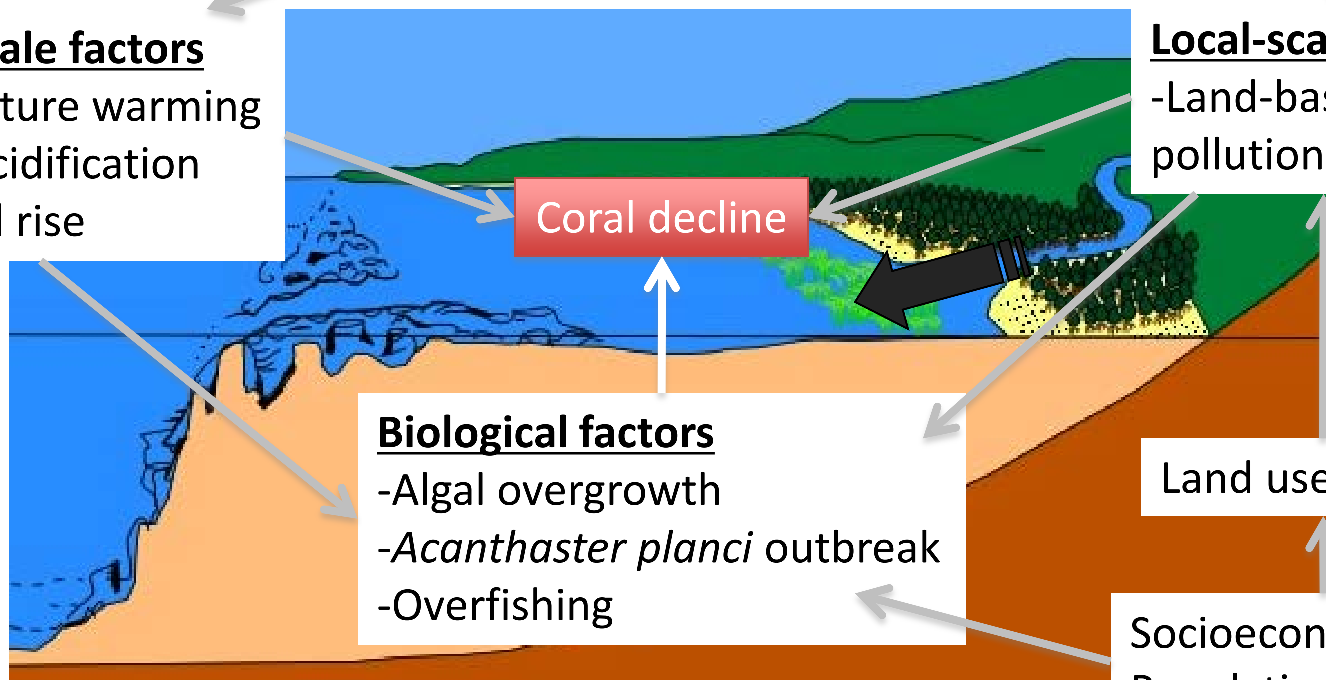
高水温により白化した
ユビエダハマサンゴ (沖縄県石垣島)
撮影:波利井佐紀

Multiple stressors on coral reefs

CO_2 emission → Climate change → Precipitation

Global-scale factors
- Temperature warming
- Ocean acidification
- Sea-level rise

Local-scale factor
- Land-based pollution

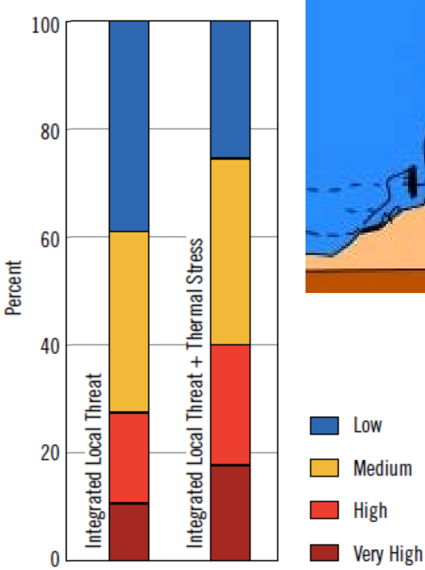


Coral decline

Biological factors
- Algal overgrowth
- *Acanthaster planci* outbreak
- Overfishing

Land use change

Socioeconomic
Population increase

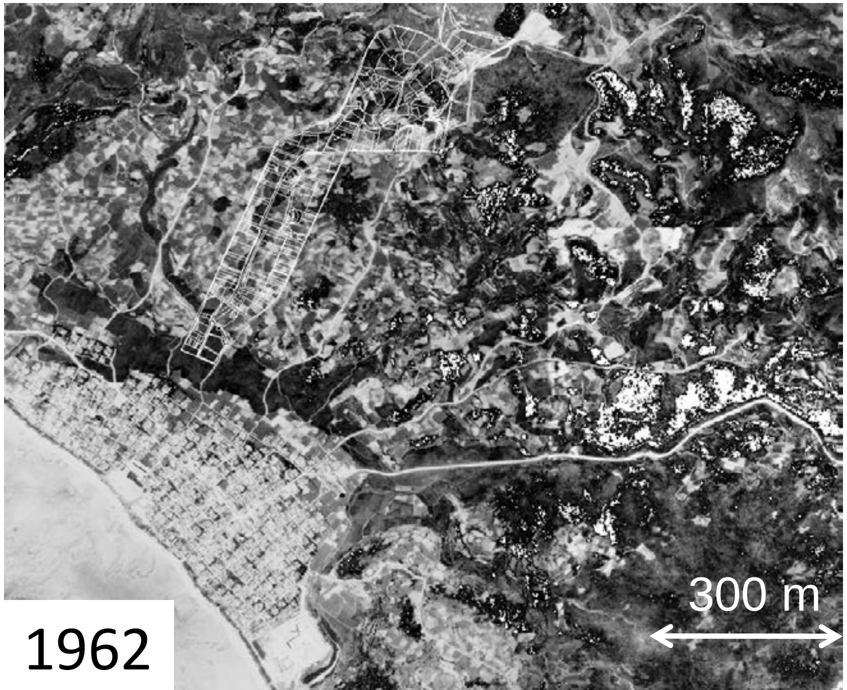


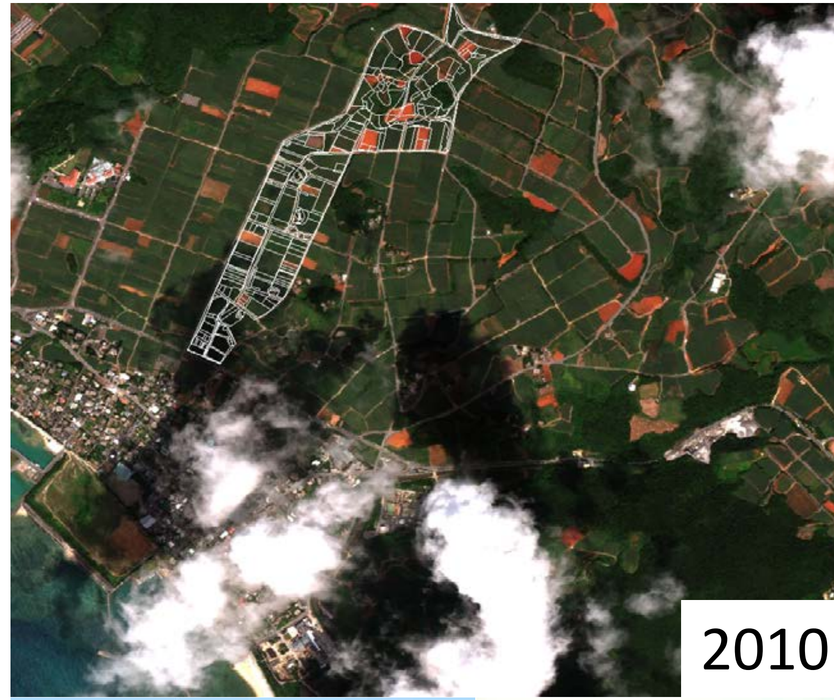
Source: Reefs at Risk revisited

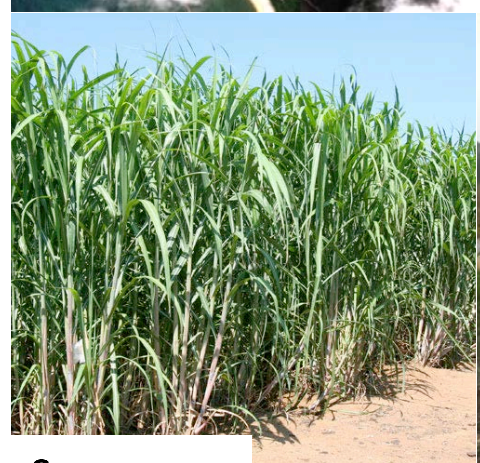
Local
60% at risk

Local + global
75% at risk

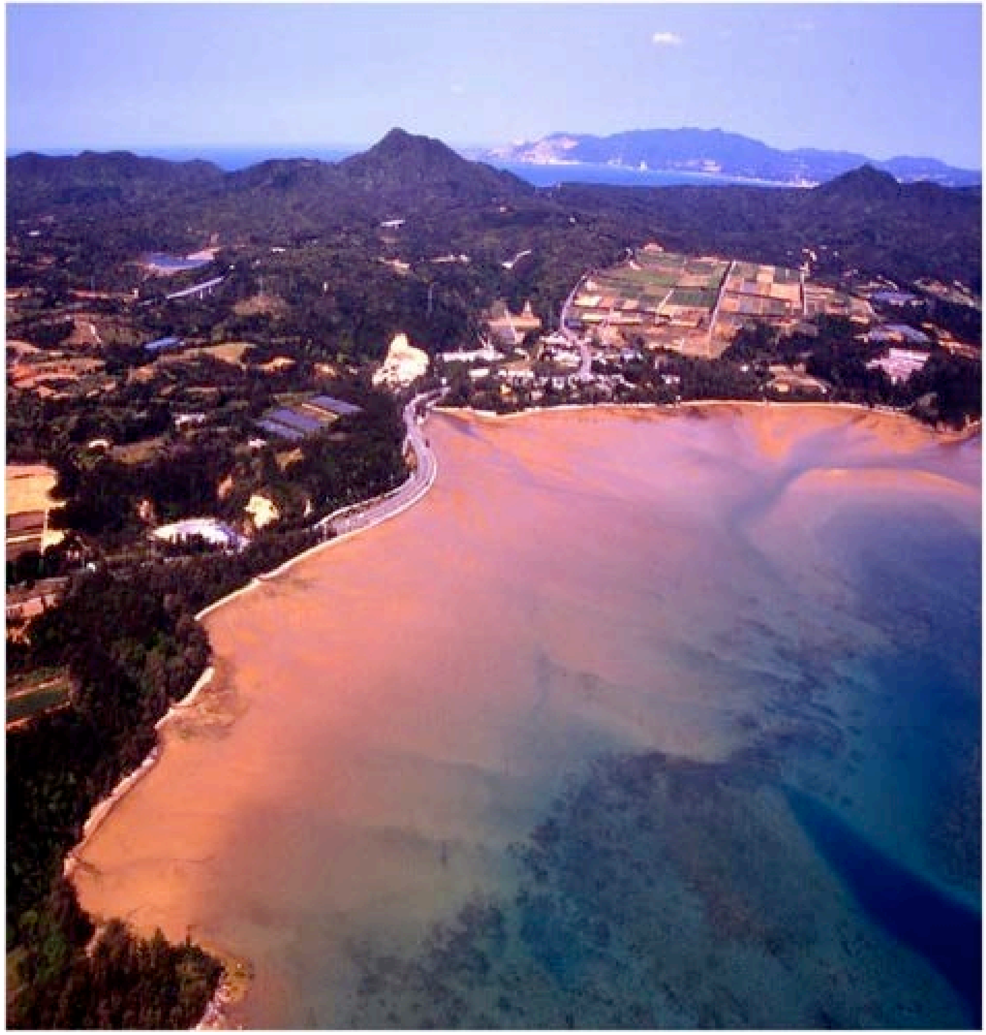
Increased sediment discharge due to land development





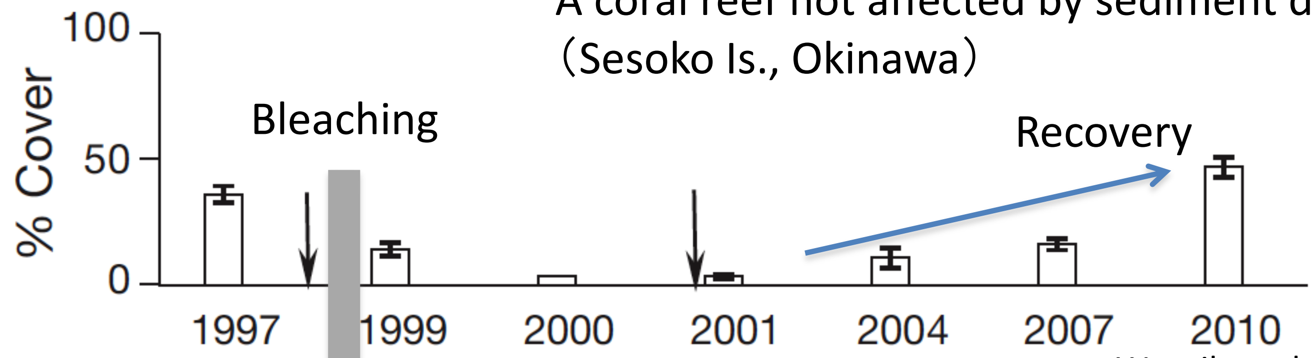


Increased sediment discharge destroys river and coastal ecosystems



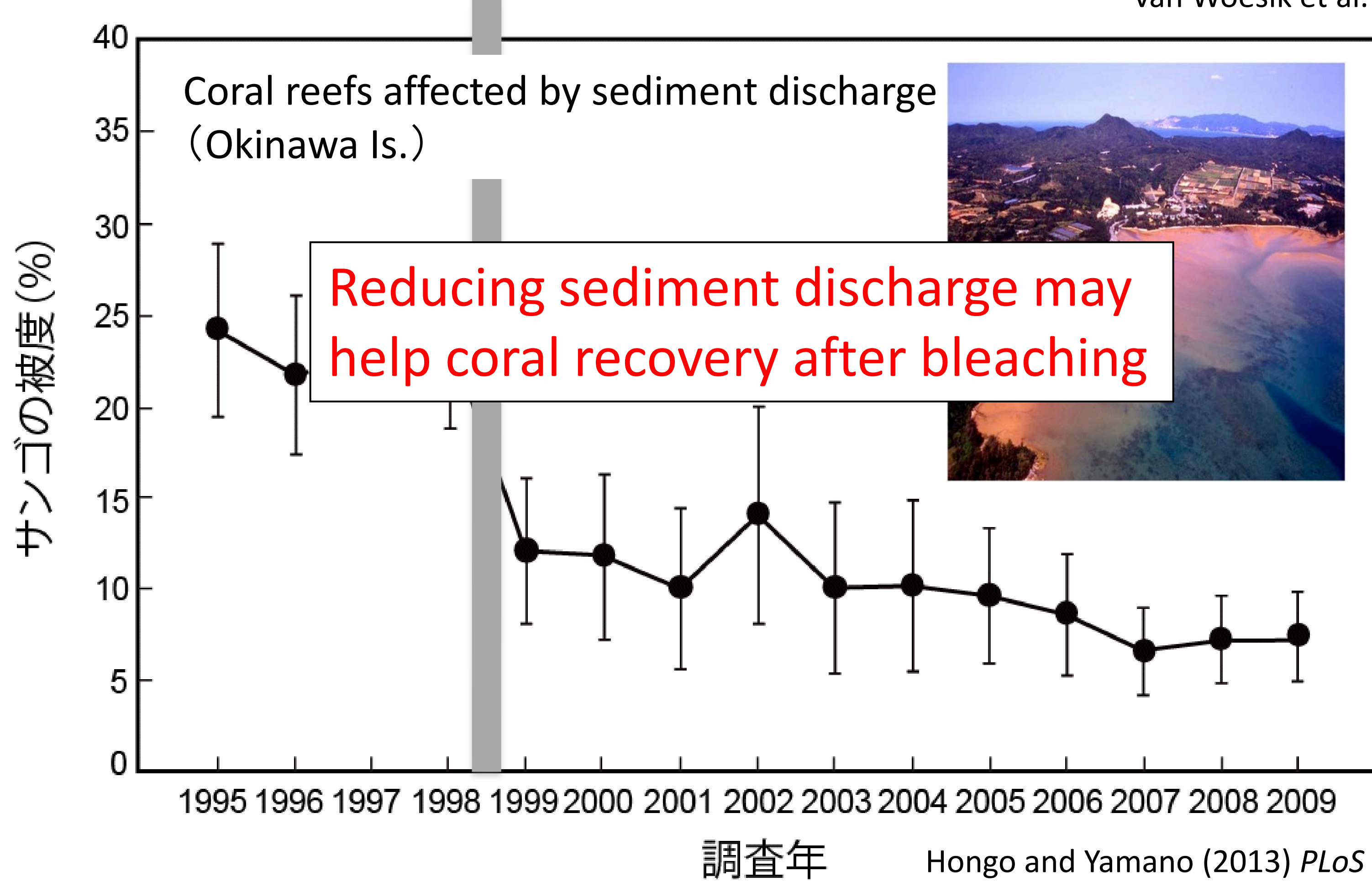
Photos provided by Okinawa Prefectural Institute of Health and Environment

A coral reef not affected by sediment discharge
（Sesoko Is., Okinawa）



van Woesik et al. (2011)

Coral reefs affected by sediment discharge
（Okinawa Is.）



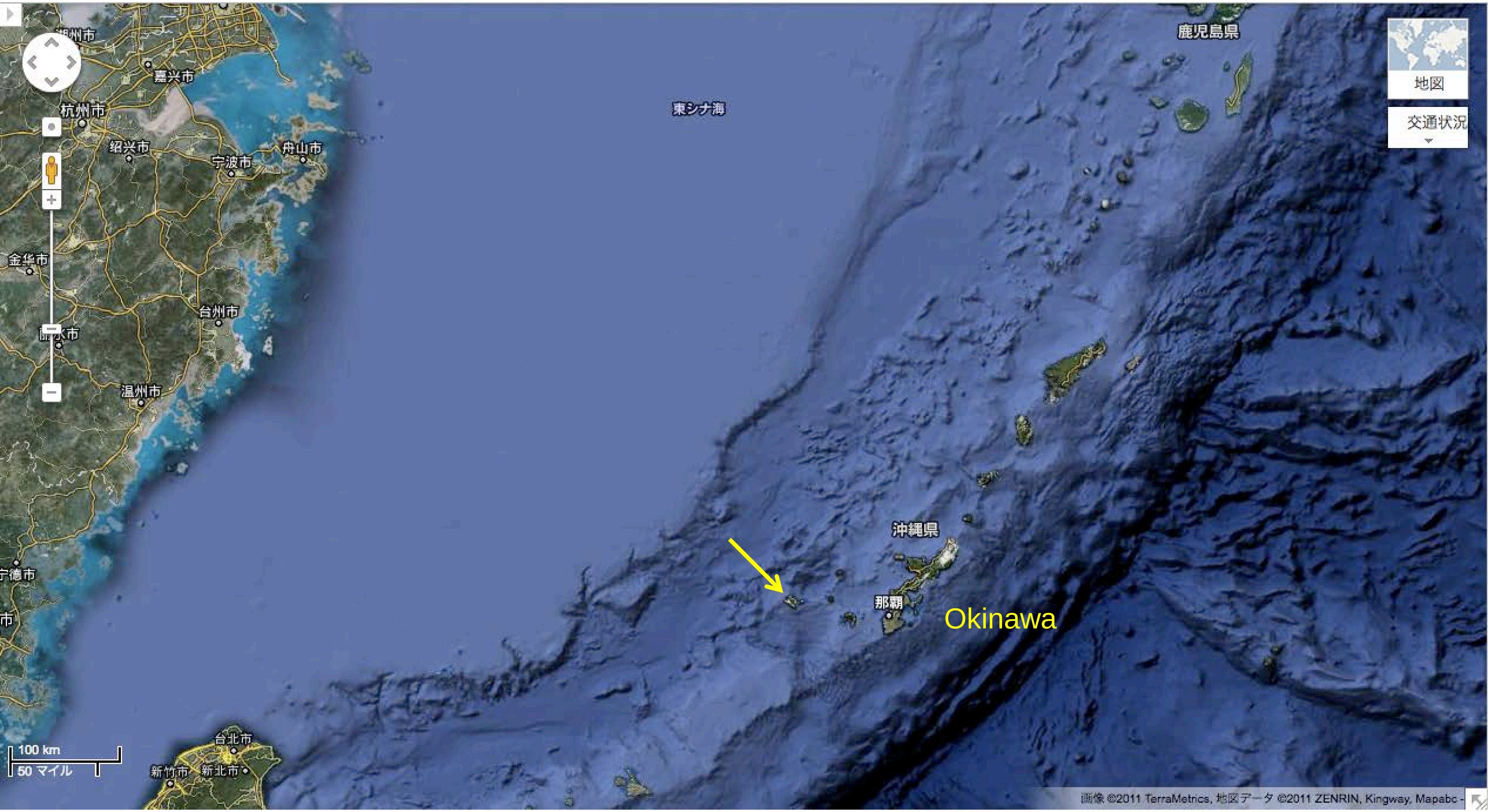
Reducing sediment discharge may help coral recovery after bleaching

Hongo and Yamano (2013) *PLoS ONE*

Outline

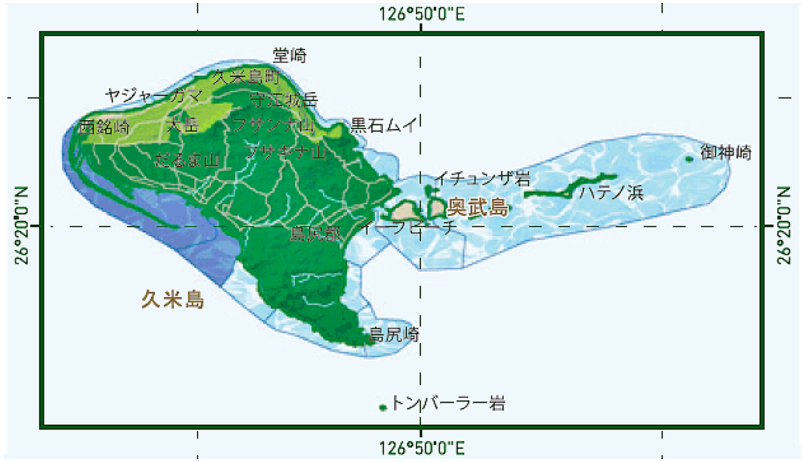
- Coral reefs at risk
- Climate change and land-based pollution
- Framework for sustainable land and coastal ecosystems

Kume Island, Okinawa, Japan





Kume Island, Japan

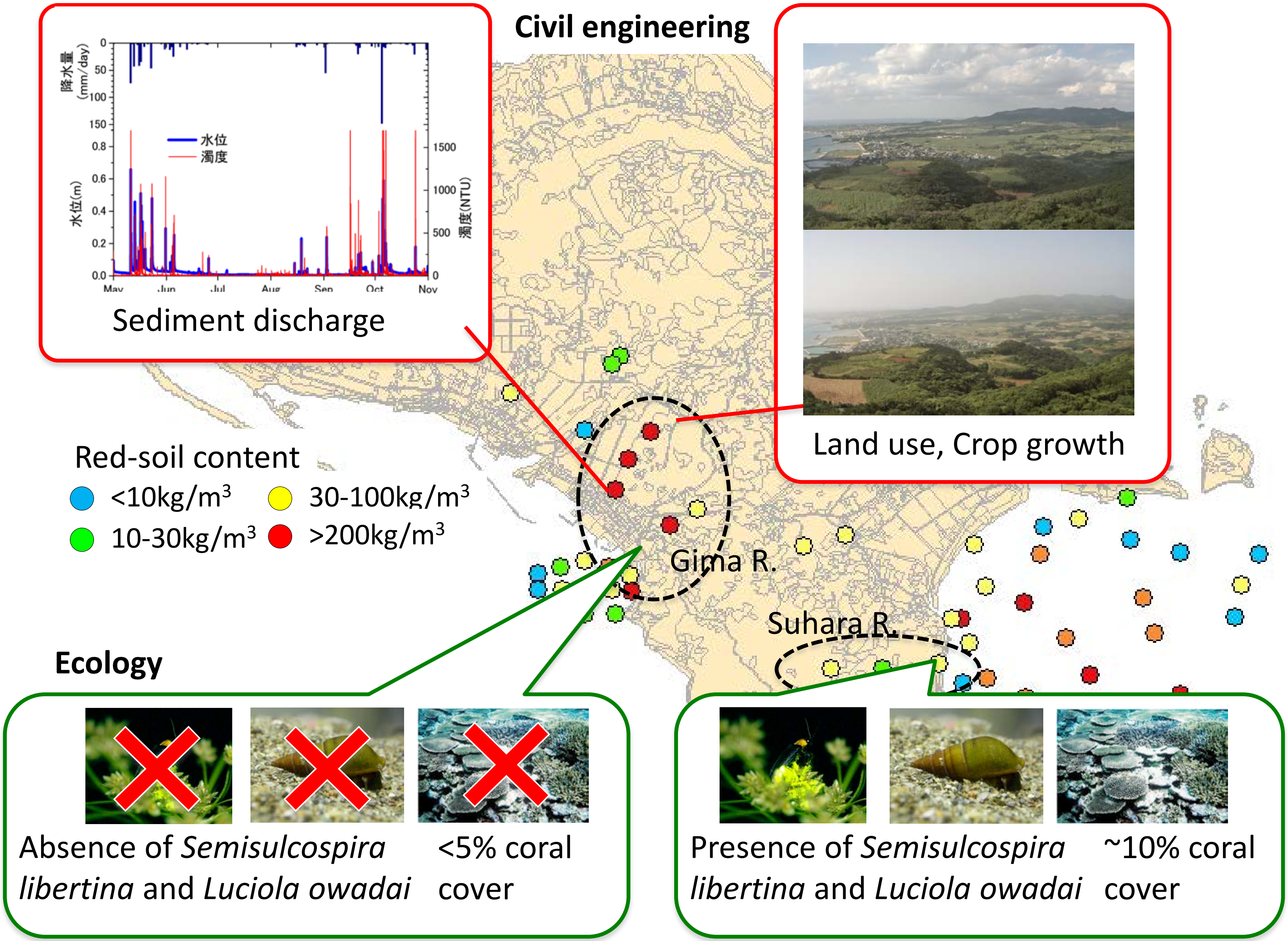


Land development (paddy field to sugar cane) and poor land management resulted in significant sediment discharge



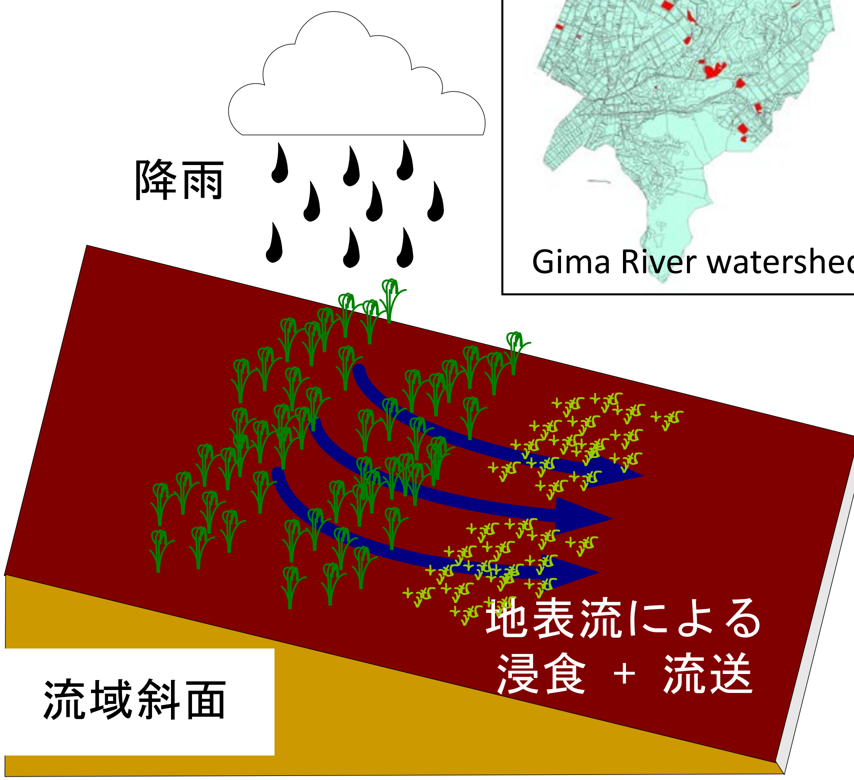
Normal state

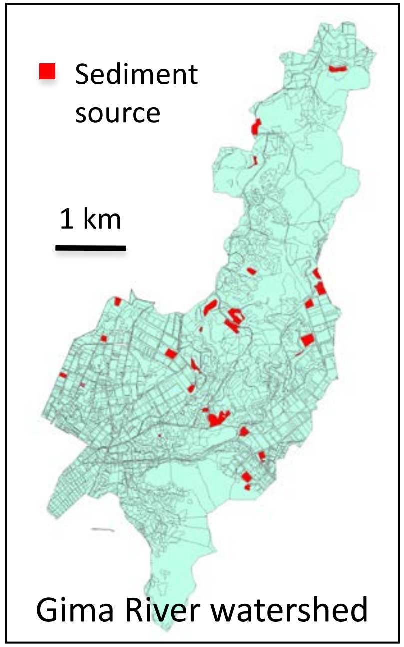

After typhoon



Defining thresholds for the amount of sediment discharge

Identifying sediment source areas by monitoring/modeling





$$q_B = A_0 \cdot \frac{(qI)^{\frac{5}{3}}}{d}$$

q_B : Sediment discharge

I : Slope

q : Surface flow

d : Sediment size

Application to crop field

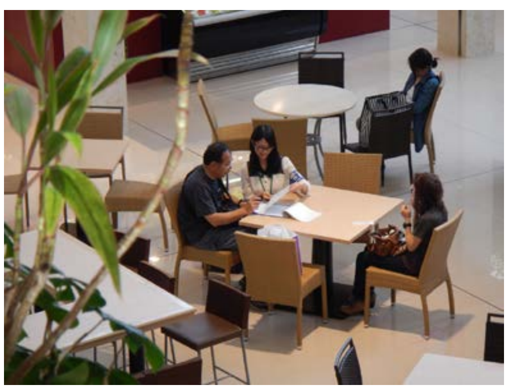
$$Q_{B^*} = \sum_i \varepsilon_i \cdot \pi_i \cdot \gamma_i \cdot A_0 \cdot \frac{(qI)^{\frac{5}{3}}}{d} \cdot L_i$$

Measures to prevent sediment discharge

Socioeconomic evaluation to implement measures to reduce sediment discharge

Interview/discussion
Cost estimation
Searching incentives

Socioeconomic

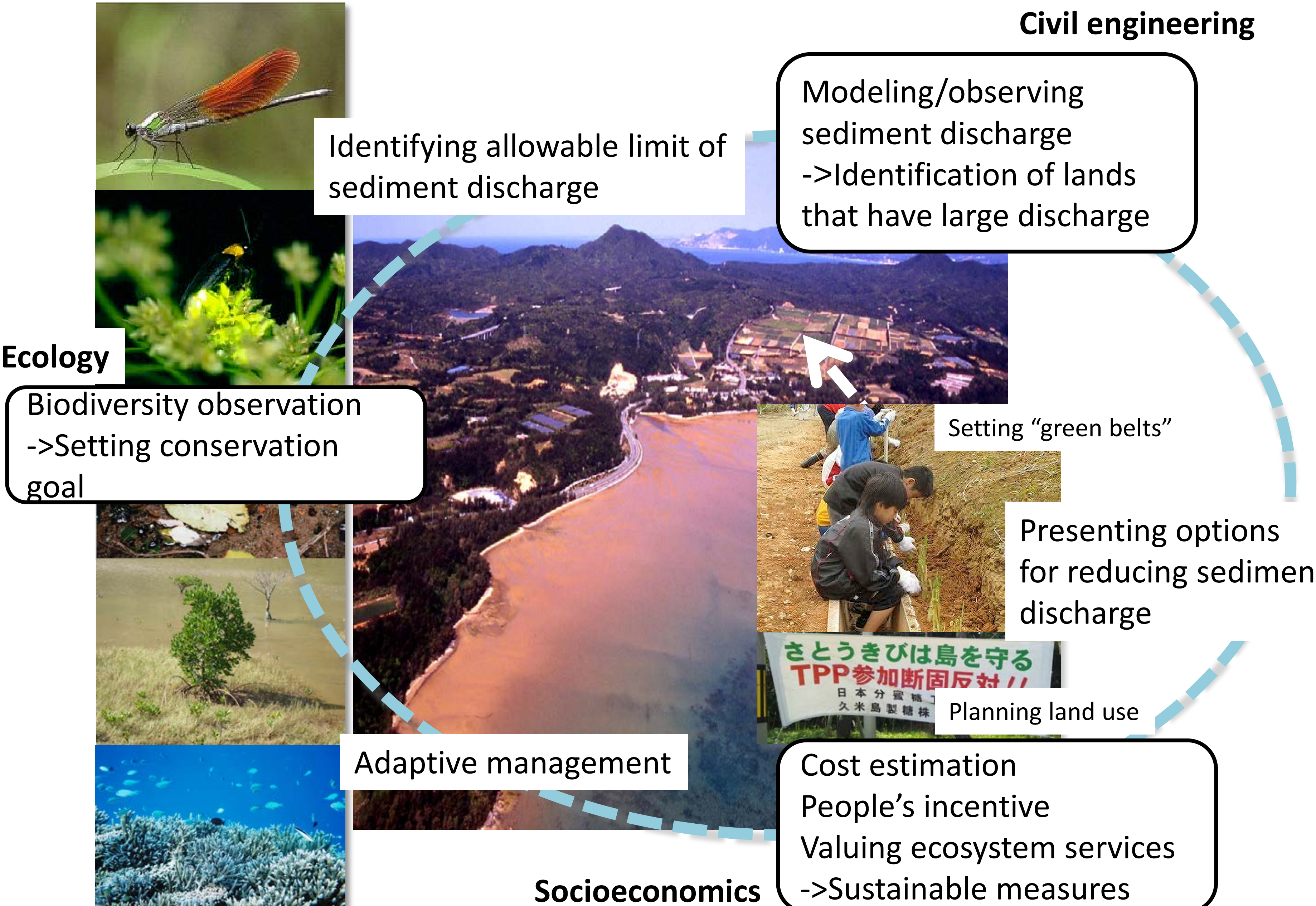


Valuing ecosystem services (tourism)

Cost/benefit analysis
Plan design
Collaboration with stakeholders

Implementation: Setting “green belts” to prevent sediment discharge from farmland with Kumejima Town and local people

Framework for sustainable management of land and coastal ecosystems



Summary

- Coral reefs are subject to multiple stressors across local (e.g., sediment discharge) to global (e.g., SST warming, ocean acidification) scales
- Increased sediment discharge not only causes coral decline but also reduces coral resilience to bleaching---Reducing sediment discharge may help coral recovery after bleaching
- A trans-disciplinary framework to couple ecology-civil engineering-socioeconomics is needed for sustainable land and coastal ecosystems