International Workshop - Session 2

Coral reefs in a changing world
- Climate change and land-based pollution issues and conservation strategies
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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 main island 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 14 km/year (Yamano et al., 2011).

Future projection of coral reef status would require consideration of another important issue, ocean acidification, caused by dissolved CO2 in seawater. Higher concentration of dissolved CO2 Cause reduction in aragonite (one of the forms of CaCO3 that construct coral skeletons) saturation state (Ωarag). We used climate model outputs for SST and Ωarag and present-day their threshold values for coral distribution to project future coral habitats. Without consideration of coral adaptation and/or acclimation, in high CO2 emission (SRES A2) scenario, coral habitats will be lost in the 2070s because of higher SST in the south and lowered Ωarag in the north (Yara et al., 2012). On the other hand, lowered CO2 emission (SRES B1) scenario, coral habitats could survive around the Ryukyu Islands even in the 2090s. This strongly supports the importance of reducing CO2 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 CO2 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:


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Hiroya Yamano
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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

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

High risk is suggested for fringing reefs close to land

“Reefs at Risk” (http://www.reefbase.org)
Multiple stressors on coral reefs

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

**Local-scale factor**
- Land-based pollution

**Socioeconomic**
- Population increase
- Land use change

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

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

Source: Reefs at Risk revisited
Outline

• Coral reefs at risk
• Climate change and land-based pollution
• Framework for sustainable land and coastal ecosystems
Sea surface temperatures (SSTs) are rising
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
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.
Multiple stressors on coral reefs

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

Local-scale factor
- Land-based pollution

Biological factors
- Algal overgrowth
- Acanthaster planci outbreak
- Overfishing

CO₂ emission → Climate change → Precipitation

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)

Coral reefs affected by sediment discharge (Okinawa Is.)

Reducing sediment discharge may help coral recovery after bleaching

van Woesik et al. (2011)
Hongo and Yamano (2013) *PLoS ONE*
Outline

• Coral reefs at risk
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Kume Island, Okinawa, Japan
Kume Island, Japan

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

Normal state
Defining thresholds for the amount of sediment discharge
Identifying sediment source areas by monitoring/modeling

\[ q_B = A_0 \cdot \frac{(qI)^3}{d} \]

- \( q_B \): Sediment discharge
- \( I \): Slope
- \( q \): Surface flow
- \( d \): Sediment size

Application to crop field

\[ Q_{B^*} = \sum_{i} e_i \cdot \pi_i \cdot \gamma_i \cdot A_0 \cdot \frac{(qI)^3}{d} \cdot L_i \]

Measures to prevent sediment discharge
Socioeconomic evaluation to implement measures to reduce sediment discharge

Interview/discussion
Cost estimation
Searching incentives

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

Civil engineering
- Modeling/observing sediment discharge
- Identification of lands that have large discharge
- Presenting options for reducing sediment discharge
- Setting “green belts”
- Planning land use

Ecology
- Biodiversity observation
- Setting conservation goal
- Adaptive management
- Identifying allowable limit of sediment discharge

Socioeconomics
- Cost estimation
- People’s incentive
- Valuing ecosystem services
- Sustainable measures
- Setting conservation goal
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