

Developing an integrated land-ocean-ecosystem model to assess terrestrial anthropogenic impacts on coral reef areas

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NakamuLab

Coral reef areas

- High biodiversity
- Complex structure
- Highly productive
- Valuable ecosystem services
- Sensitive to environmental changes



Fringing coral reef, Ishigaki Island.



Shiraho Reef, Ishigaki Island.

Multiple stressors

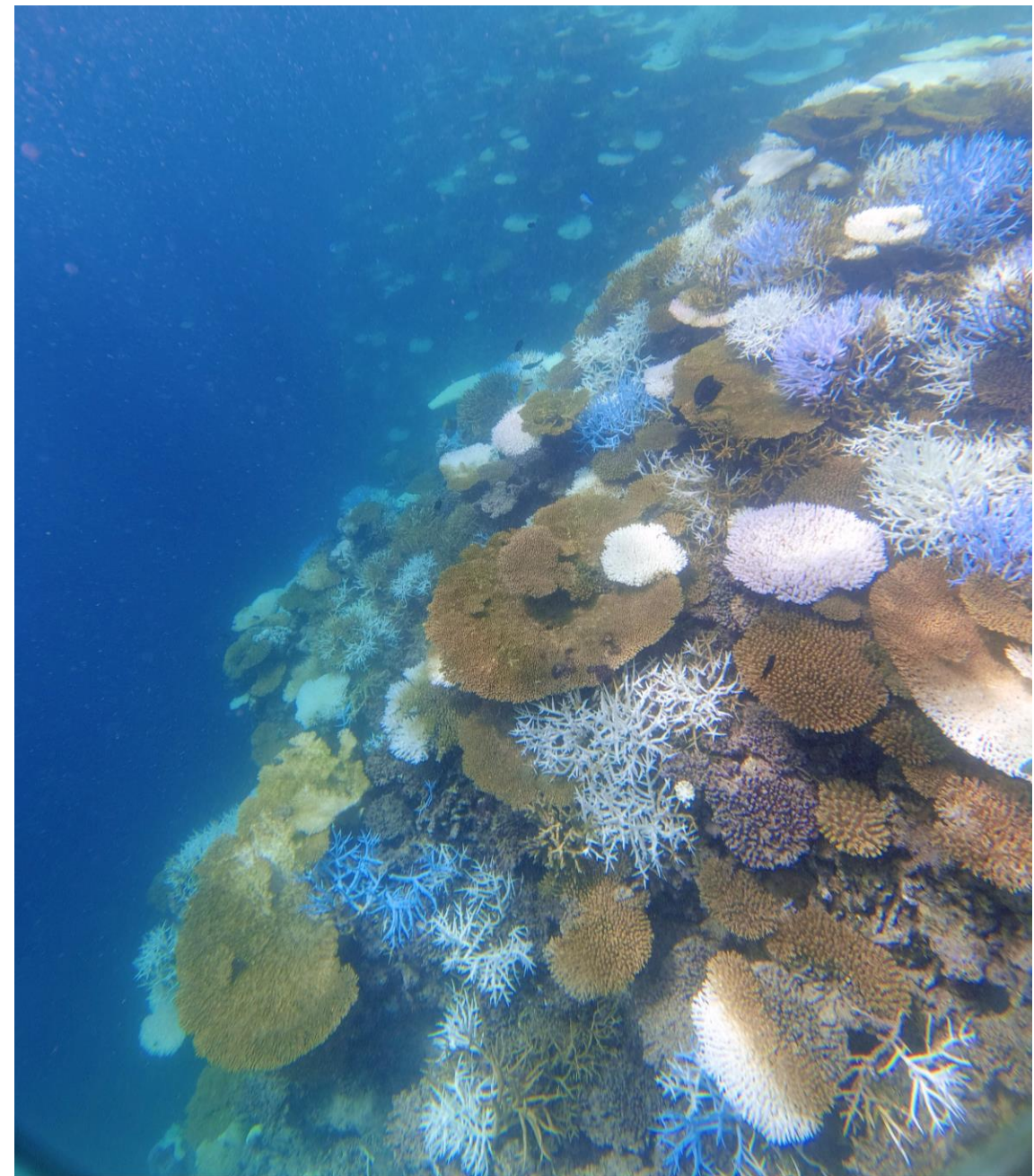
Coral reefs around the world are facing significant impacts by climate change and socio-economic development.

Global scale:

Climate change, global warming, ocean acidification.

Local scale:

Nutrient runoff, coastal development, Crown-of-Thorns Starfish (COTS), low water quality.



Coral bleaching at Fukido reef, Ishigaki Island. September 2022.

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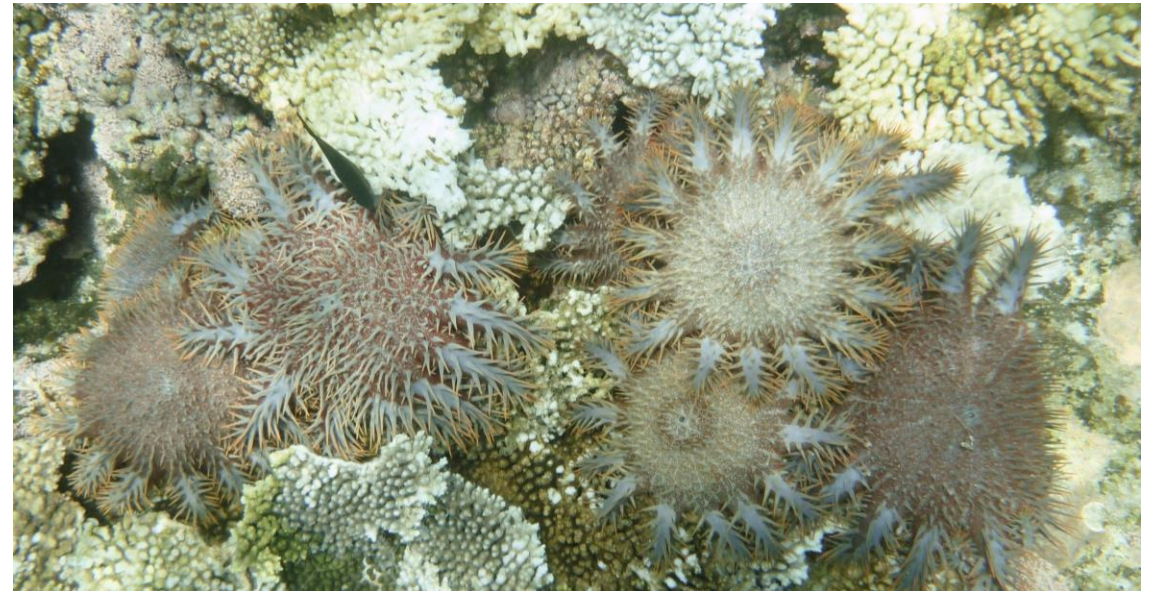
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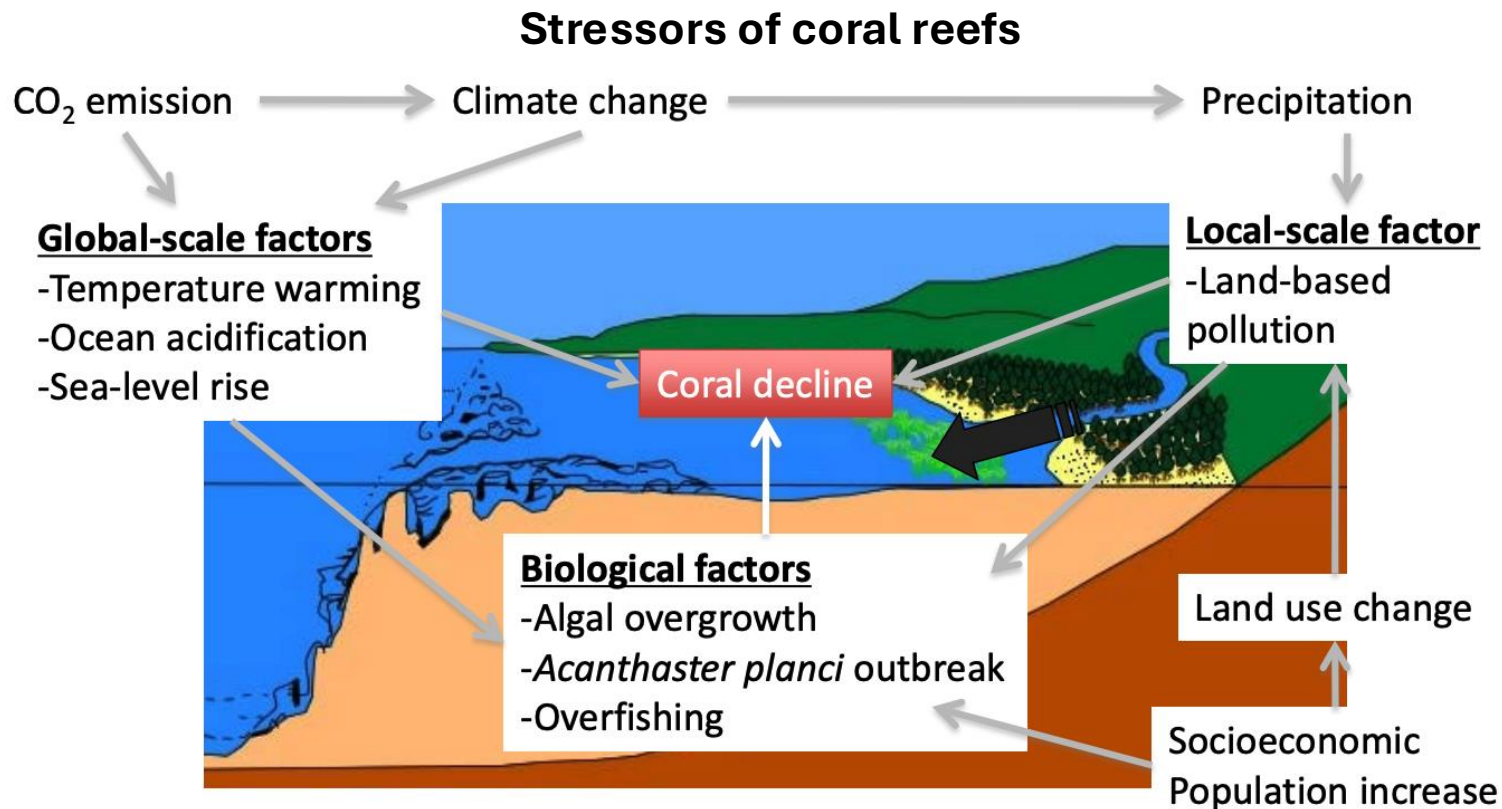
Red soil runoff. Photo: OIST, 2019



Ishigaki Island, 2011. Photo: Takashi Nakamura

An interdisciplinary challenge

The connections between land use and marine ecosystems are not always obvious.



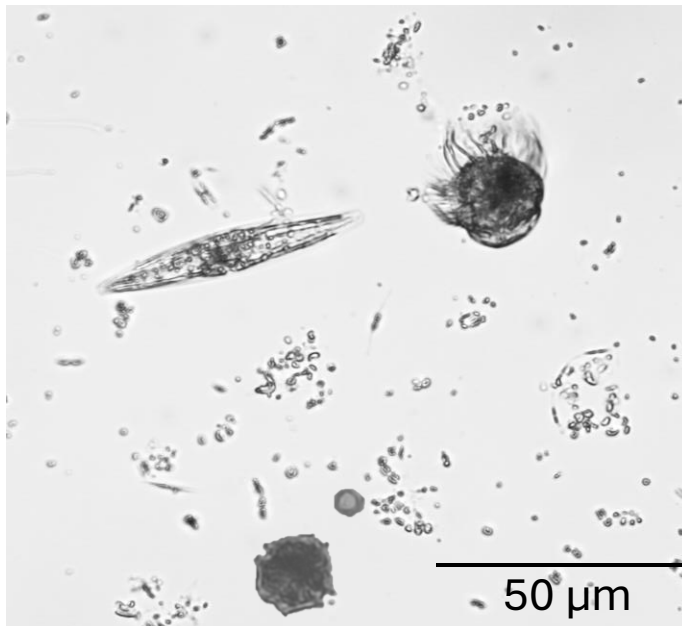
Yamano & Watanabe (2016)

The cycles of the key nutrient elements **nitrogen (N)** and **phosphorus (P)** have been massively altered by human activities.

It is essential to understand how primary production across diverse ecosystems is (or is not), limited by N and P (Elser et al., 2007).

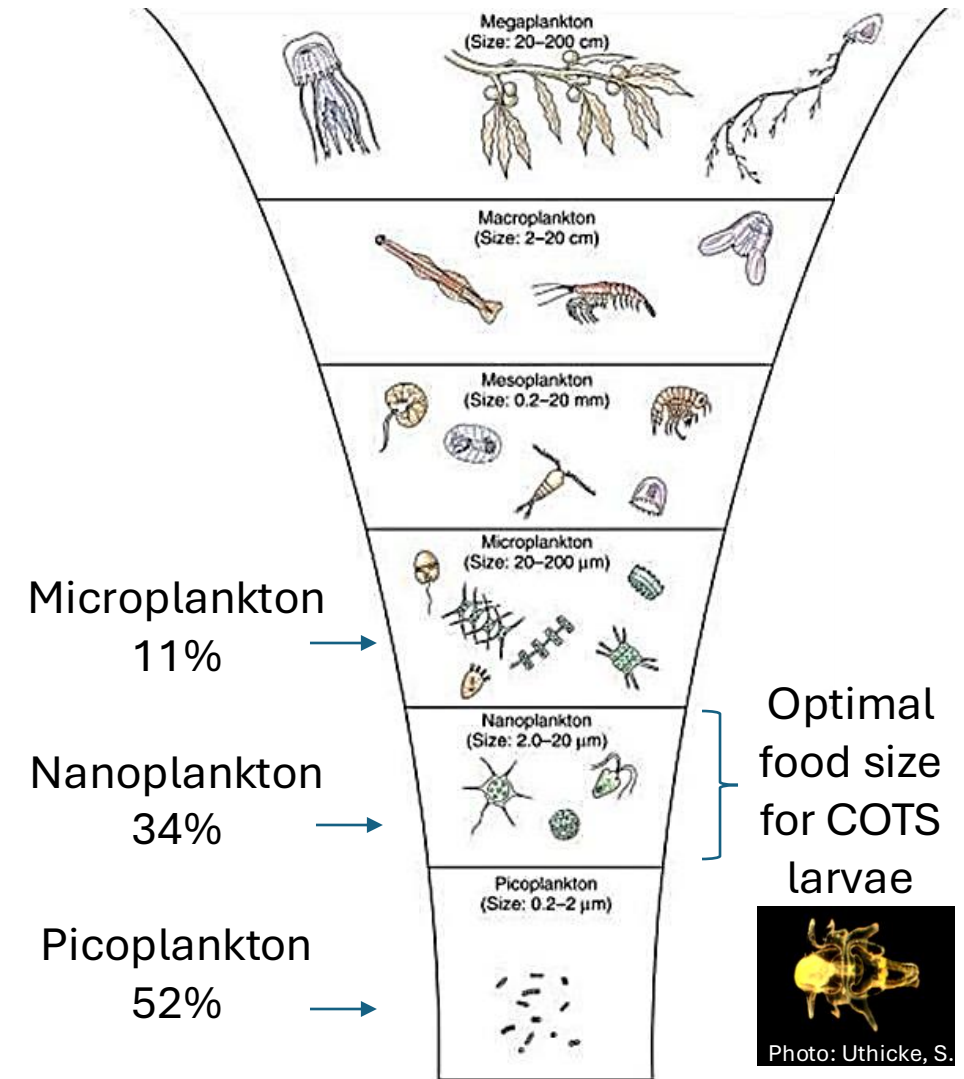
Low-trophic ecosystem in coral reefs

- Phytoplankton link inorganic nutrients to marine food webs.
- In oligotrophic marine coastal areas, small phytoplankton species tend to dominate (e.g., *Synechococcus*, *Prochlorococcus*).
- However, after nutrient runoff, the dynamics of phytoplankton populations can change significantly.



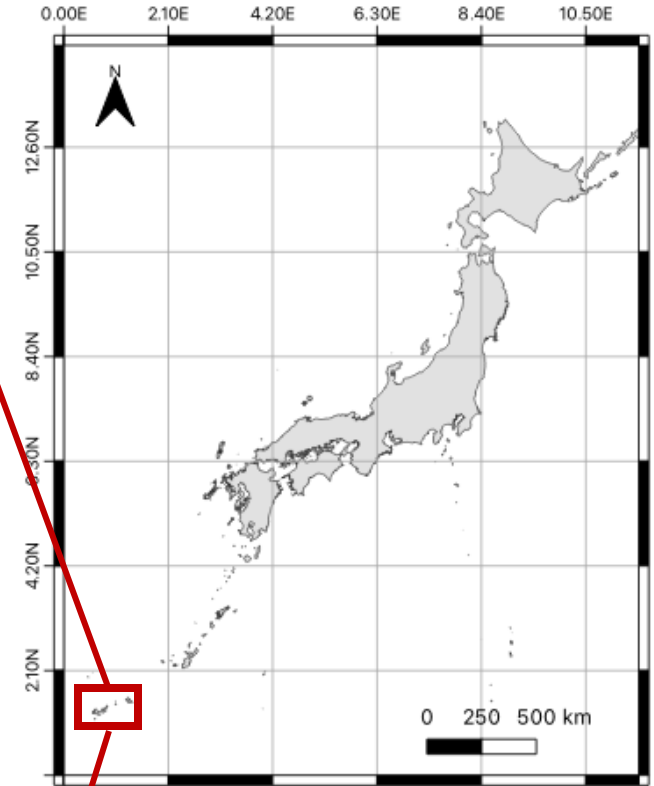
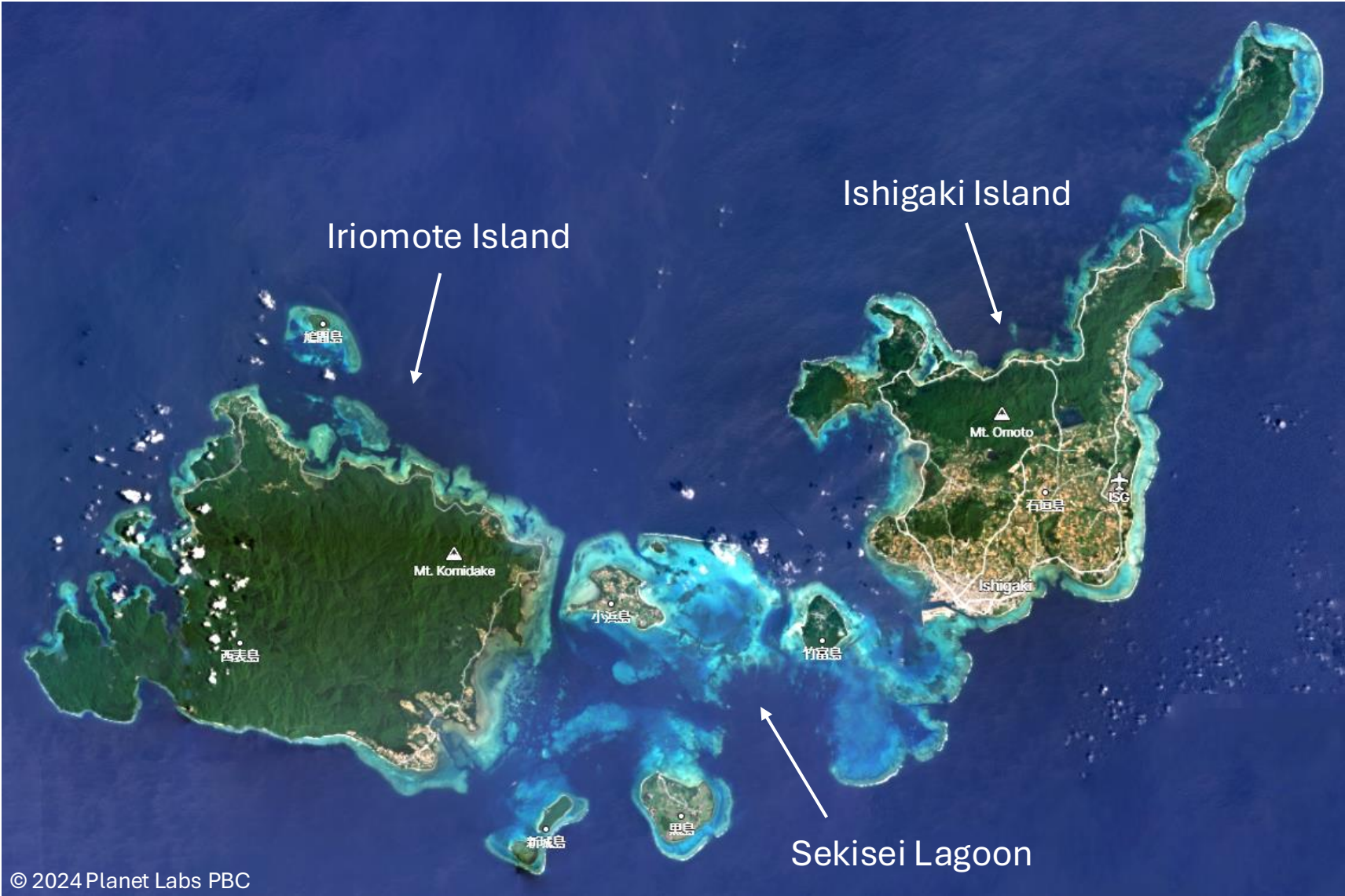
Plankton classification

Castro & Huber, 2015



Chlorophyll-*a* contribution in Okinawa
(Tada et al., 2016)

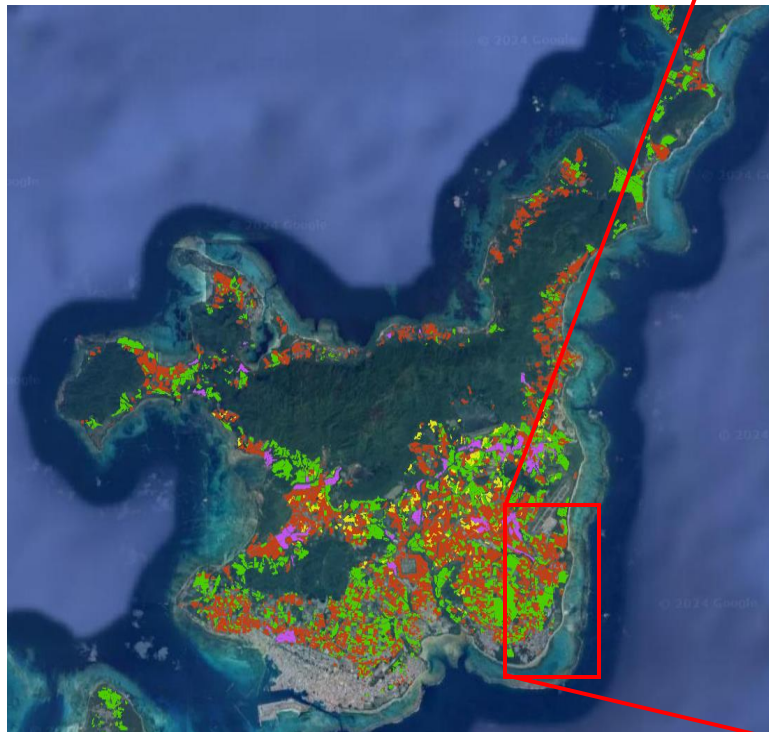
Study Site: Yaeyama Islands, Okinawa



Sekisei Lagoon:
The largest coral reef
area in Japan

Agriculture in Ishigaki Island

In the Shiraho Reef area, river runoff and groundwater are important sources of nutrients (Blanco et al., 2010)



Land use

- Rice
- Sugar cane
- Pineapple
- Grassland

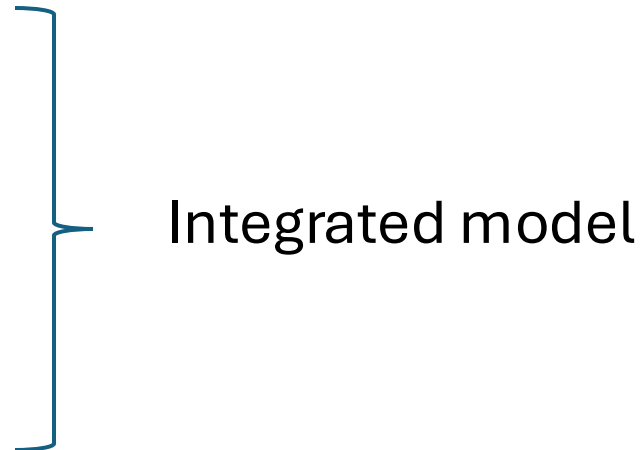


Key questions and objectives

- How does a coral reef ecosystem respond to multiple environmental changes?
- How to mitigate and recover from ecosystem degradation?
- To develop a “Socio-Ecological System” framework for sustainable use of ecosystem services

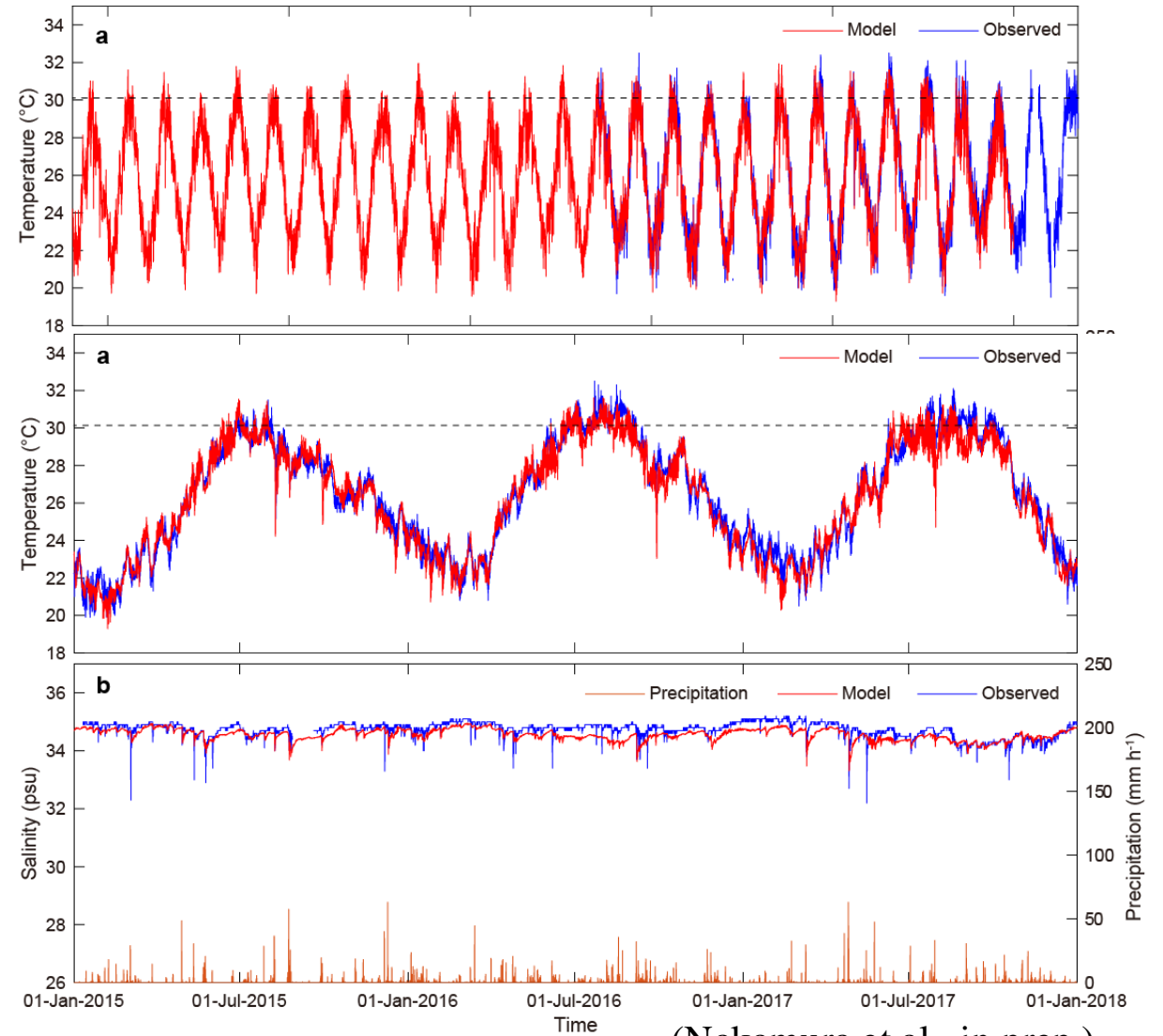
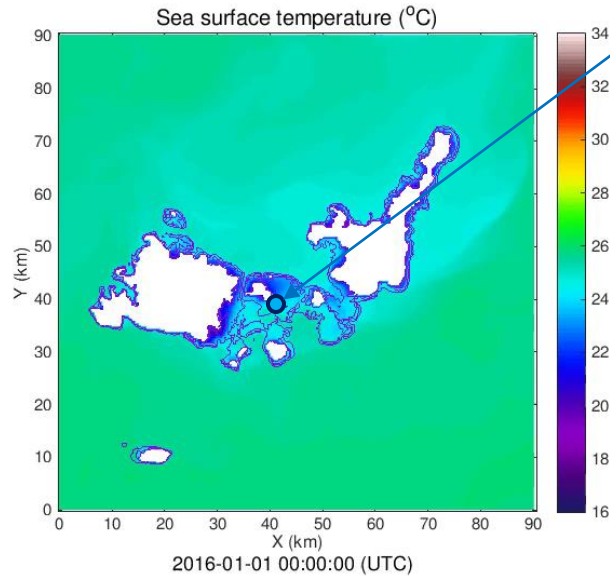
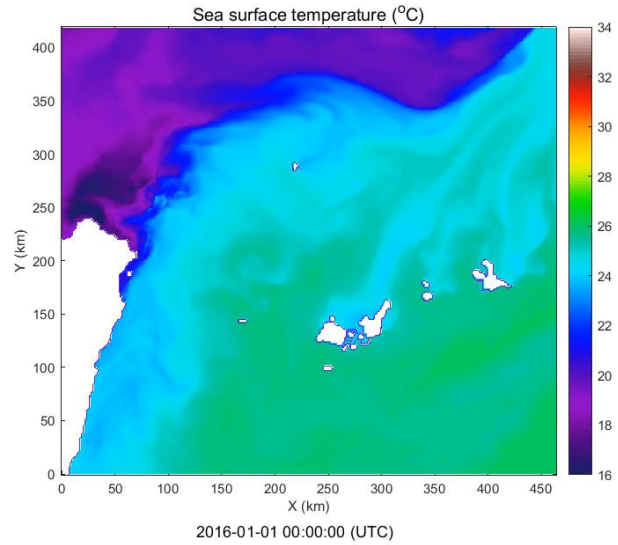
Methodological Framework

- 1) Ocean (3D circulation model)
- 2) Land (Watershed model)
- 3) Marine coastal ecosystem
(low-trophic ecosystem model)



Long-term hindcast simulation for reproducing coral reef environments using COAWST*

Ocean

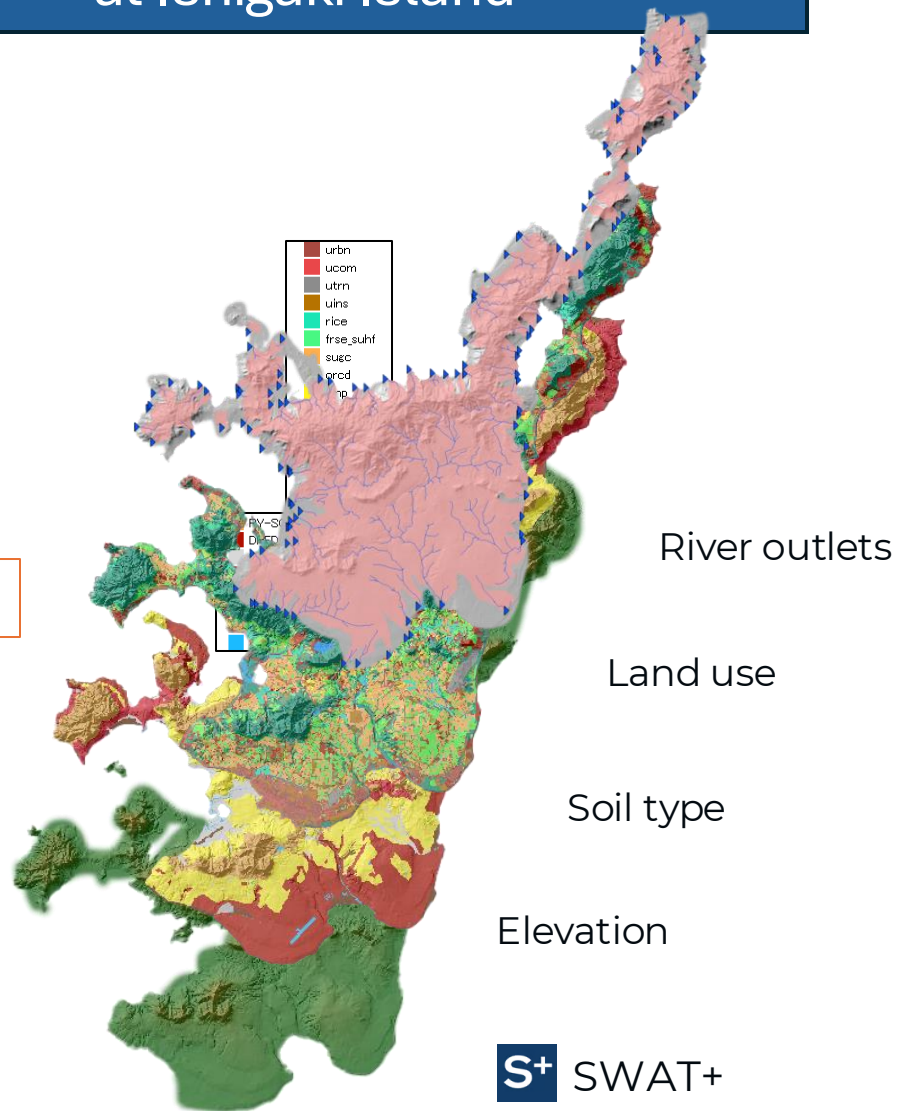


(Nakamura et al., in prep.)

*Coupled-Ocean-Atmosphere-Wave-Sediment Transport Modeling System (Warner et al., 2010)

Watershed simulations and fieldwork at Ishigaki Island

Land

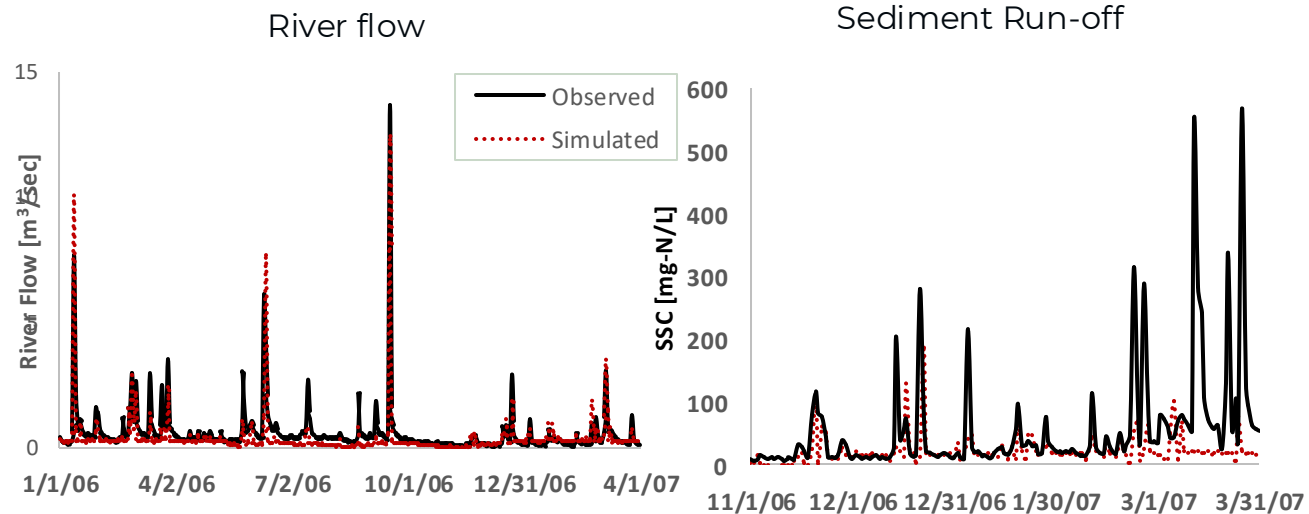
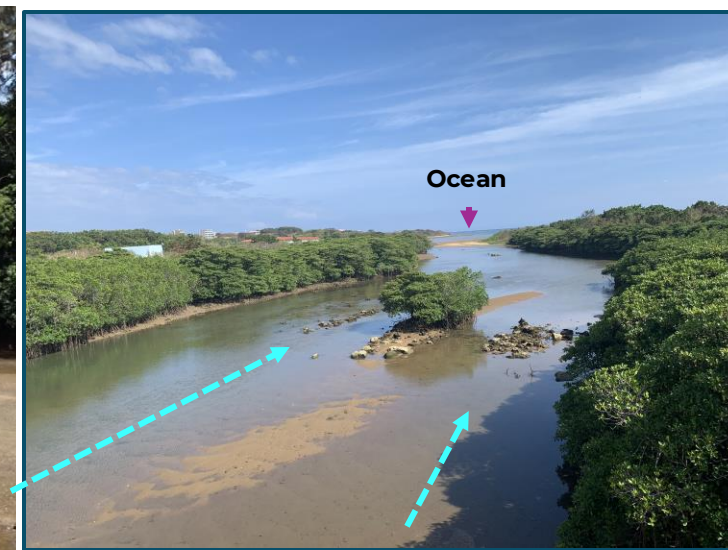


Soil and Water Assessment Tool (Bieger et al., 2017)

Nutrient measurements



River water discharge



Todoroki river

Low-trophic ecosystem and sediment model from field-based experiments



Natural phytoplankton community

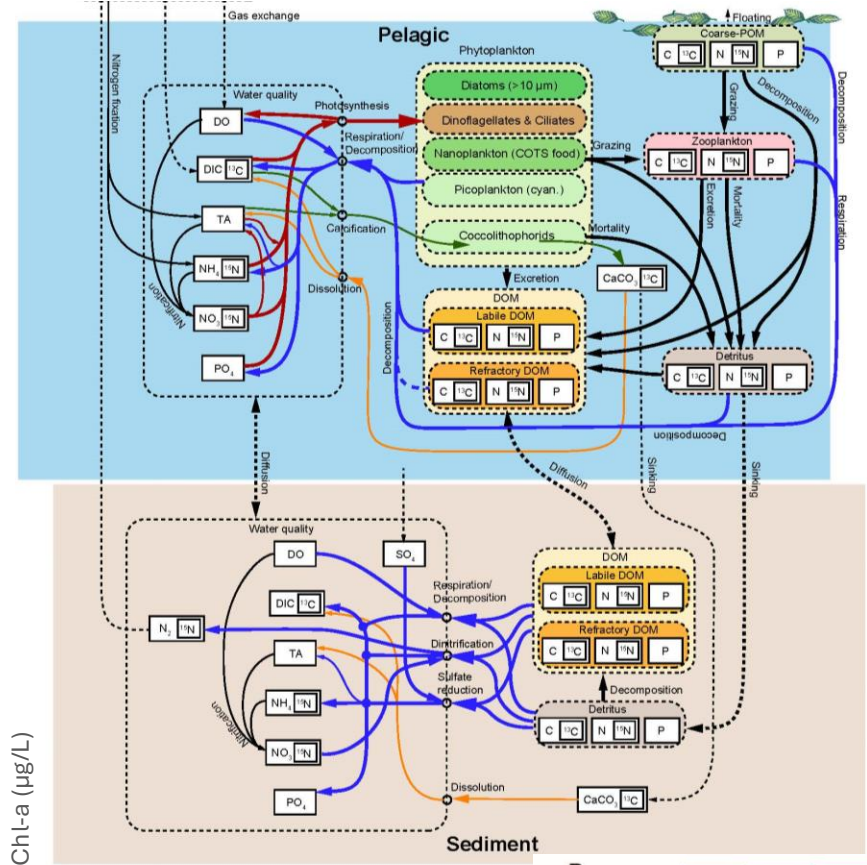
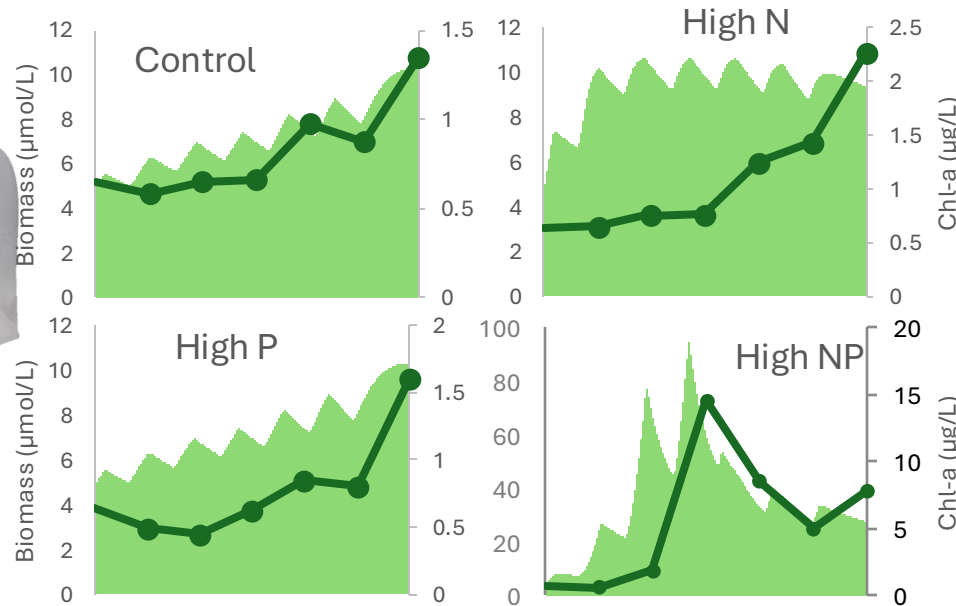
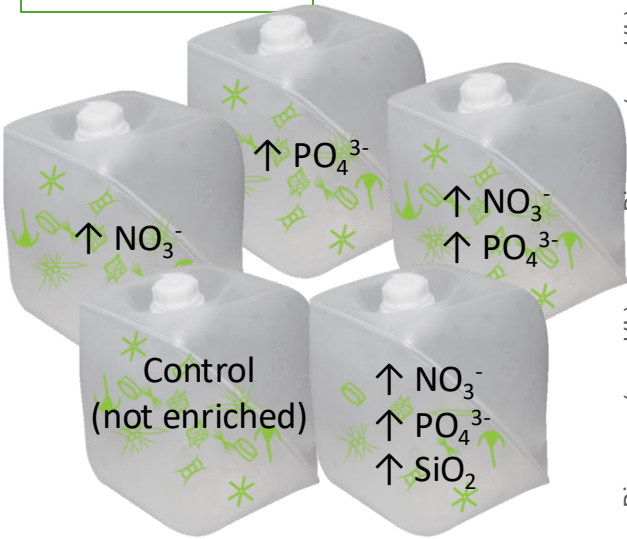


Nutrient enrichment

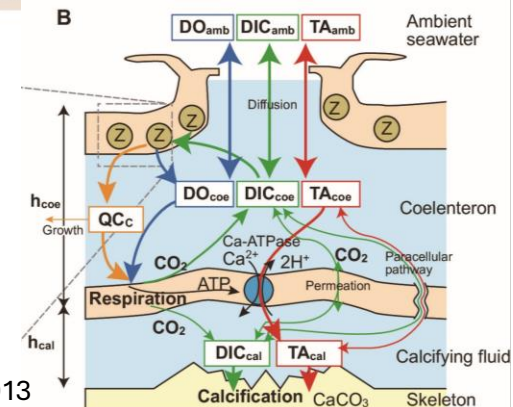


Incubation (7 days)

Coastal Ecosystem

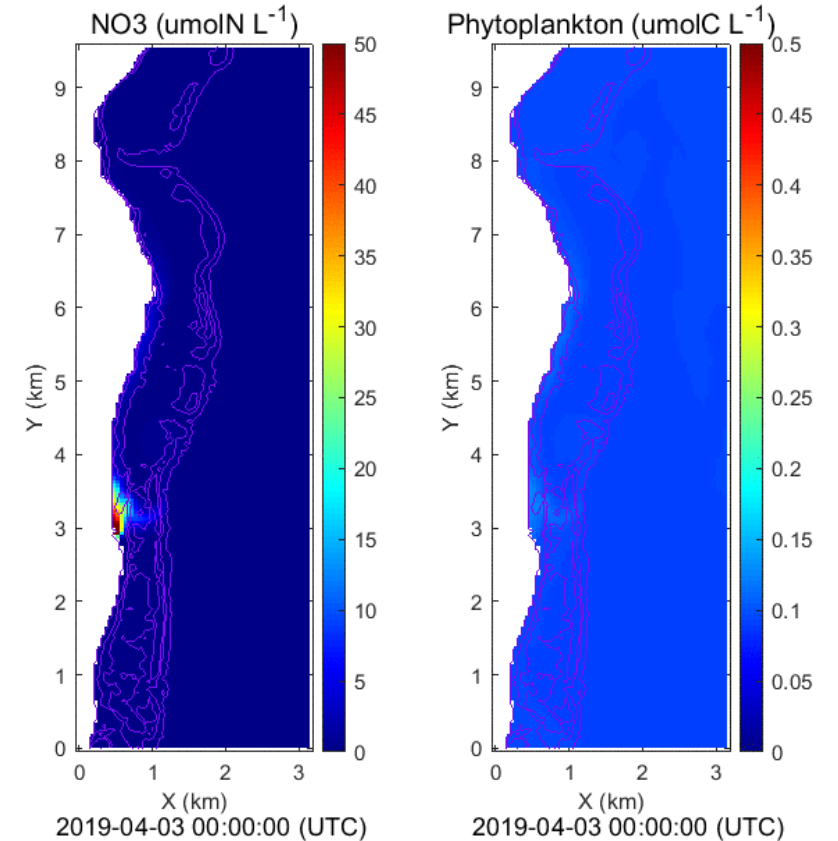


Simulation (C biomass)
Observed Chl-a pattern



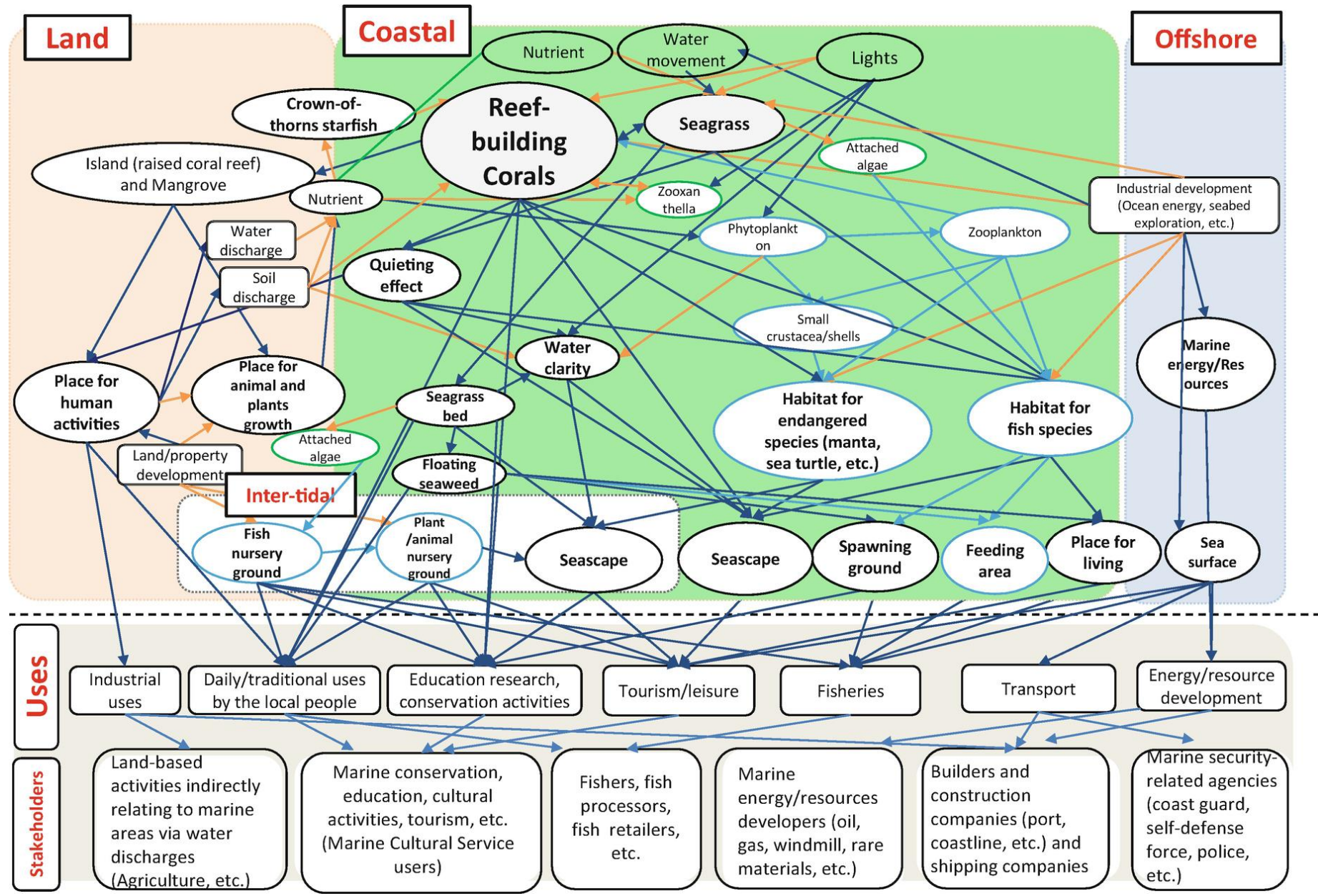
Implications for coral reef management and coastal areas

- **Enhanced modeling accuracy** from long-term monitoring, observation, and experiments.
- **Impactful and accessible visual representation** of possible scenarios.
- Illustrate the **links** between terrestrial activities and coral reefs and emphasize the importance of integrated coastal zone management and regulation of land use activities
- Evaluate possible future scenarios to suggest **management strategies**, and simulate policy scenarios.
- Useful approach to **set limits** for nutrient runoff in coastal areas, use of fertilizer, and land use.



Policy Interventions

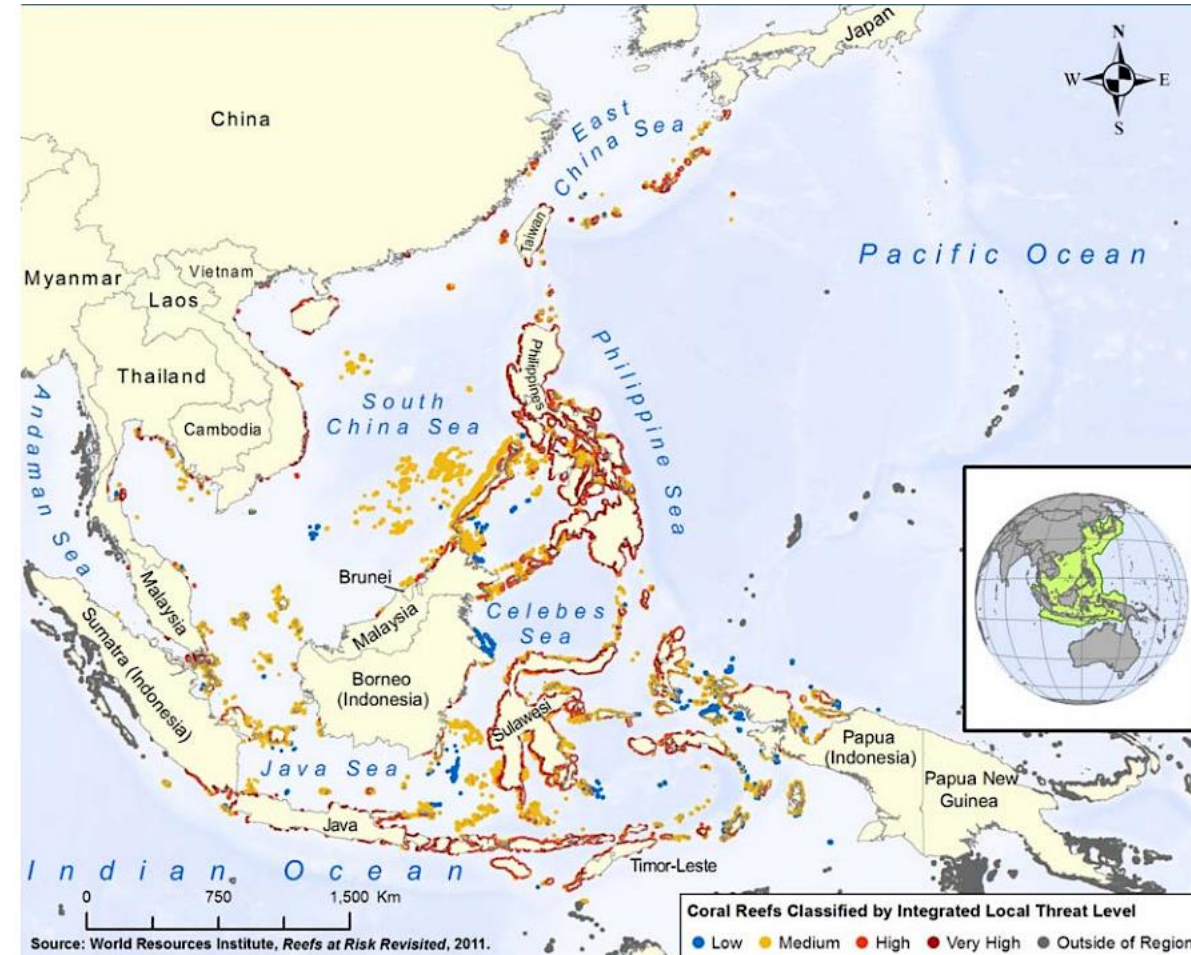
Interrelationship among the main ecosystem structures, ecosystem functions, ecosystem use types, and stakeholders in Sekisei Lagoon, Okinawa



Challenges in interdisciplinary research

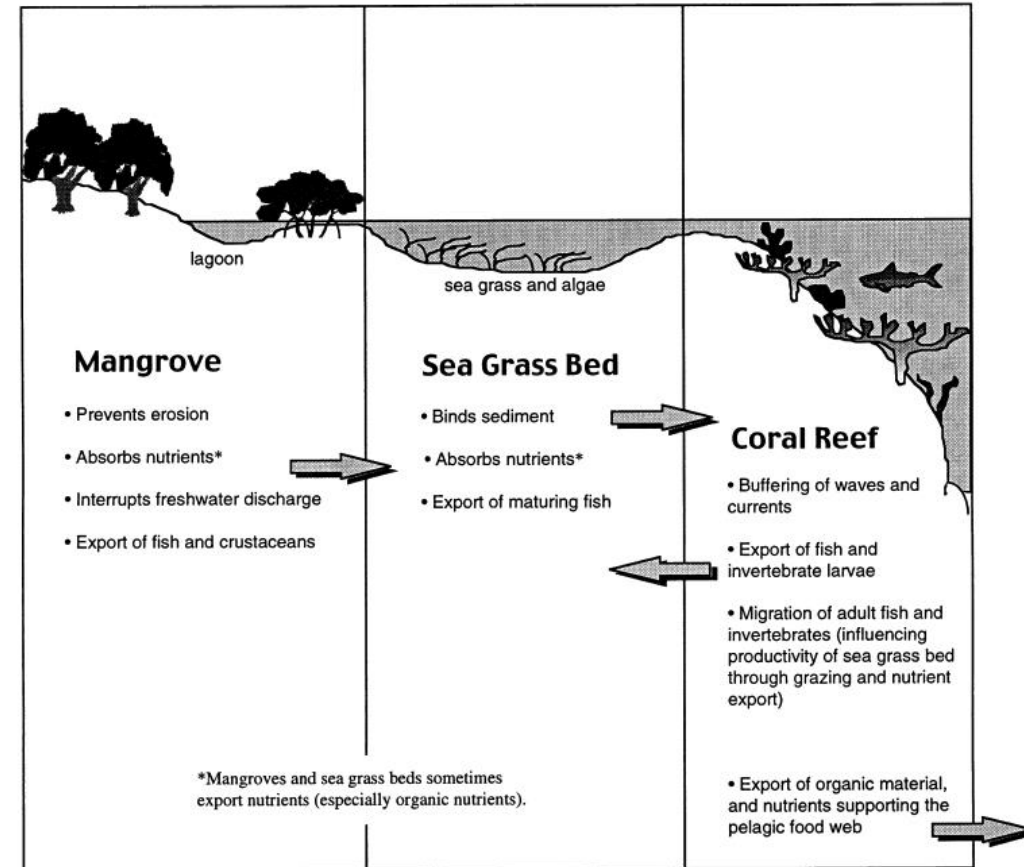
- Biologists vs Modelers (as simple as possible, as complex as needed)
- Specificity of the model (tropical coastal areas)
- Transition from Interdisciplinary to Transdisciplinary
- Communication with general public and stakeholders
- Socioeconomic-related papers and datasets from the area are only available in Japanese

Reefs at risk in Southeast Asia



Conclusions and future directions

- Interdisciplinary research is essential to understand complex land-ocean interactions.
- Monitoring and modeling are important tools to evaluate and implement measures to reduce terrestrial influence on coastal areas.
- The integrated land-ocean-ecosystem model provides a comprehensive tool for assessing the impacts of terrestrial nutrient runoff on marine ecosystems.
- Effective management of terrestrial activities is needed to mitigate adverse impacts on coral reefs.
- This approach can improve the study of carbon fluxes and nutrient cycling, especially under climate change scenarios. However, other components such as mangroves and seagrasses should be included.



Adopted from White (1986) and Ogden (1988).

(Moberg and Folke, 1999)



Thank you!

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