The Grand Challenges of WPI-AIMEC: Executive Summary

Toshio Suga[1,2], Fumio Inagaki[1,2] *, Kentaro Ando[1,2], Michio Kondoh[2], S. Lan Smith[1,2], Keith Rodgers[1,2], Toyonobu Fujii[2], Michio Kawamiya[1,2], Hanani Adiwira[1], Maki N. Aita[2], Vani Novita Alviani[1], Cheryl Lewis Ames[1], Kamrun Naher Azad[1], Ettore Barbieri[2], Batdulam Battulga[1], Jonathan Derot[2], Diego Deville[1], Tetsuichi Fujiki[2], Jimena García-Rodríguez[1], Tomoko Hamabata[1], Masumi Hasegawa-Takano[2], Andrew Hirzel[3], Tatsuhiko Hoshino[1,2], Benjamin Horton[4], Shigeki Hosoda[2], Minoru Ikeda[1], Yasufumi Iryu[1], Yoichi Ishikawa[1,2], Kota Ishikawa[1], Sabine Kasten[5], Jamie M. Kass[1], Satoshi Katayama[1], Shinya Kouketsu[1,2], Gaku Kumano[1], Zhen Lin[1], Jutarak Luang-on[2], Hiroshi Murakami[1,6], Yuriko Nagano[2], Takashi Nakagawara[1], Tomoe Nasuno[2], Goh Nishitani[1], Riko Oki[1,6], Takeshi Obayashi[1], Yuichi Okayama[1,2], Yusaku Ohta[1], Shuhei Ono[7], Yutaka Osada[1], Bo Qiu[3], Namal Rathnayake[2], Kelvin Richards[3], Niklas Schneider[3], Takashi Sakamaki[1], Yusuke Sasaki[1], Kanako Sato[2], Masahito Shigemitsu[2], Eko Siswanto[2], Kugako Sugimoto[1], Shusaku Sugimoto[1], Yoshihisa Suyama[1], Kaoru Tachiiri[2], Hiromi Takahata[2], Hideko Takayanagi[1], Akifumi S. Tanabe[1], Hiroaki Tatebe[2], Fumiaki Tomita[1], Tsunaki Iida[1,2], Gerlien Verhaegen[2], Clara R. Vives[2], Lael Wakamatsu[2], Shingo Watanabe[1,2], Shuya Wang[1], Angelicque White[3], Nadine Wood[1], Baolan Wu[1], Shang-Ping Xie[8], Sayaka Yasunaka[1,2], Jiwei Yang[1], Akinori Yabuki[1,2], Yosuke Yamada[2], Alan Yee[1], Taichi Yokokawa[2], Nan Yuan[1], William F. McDonough[1], and Kimio Hanawa[1,2]

1. Advanced Institute for Marine Ecosystem Change (WPI-AIMEC), Tohoku University, Sendai 980-8578, Japan
2. WPI-AIMEC, Japan Agency for Marine Earth Science and Technology, Yokohama 236-0001, Japan
3. WPI-AIMEC, International Pacific Research Center, University of Hawai‘i at Mānoa, Honolulu, HA 96822, USA
4. School of Energy and Environment, City University of Hong Kong, Kowloon, Hong Kong SAR, China
5. Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven 27570, Germany
6. Earth Observation Research Center, Japan Aerospace Exploration Agency, Tsukuba 305-8505, Japan
7. Department of Earth, Atmosphere and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
8. Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA 92093, USA

*Corresponding author: Fumio Inagaki
Email: inagaki@jamstec.go.jp; fumio.inagaki.a5@tohoku.ac.jp

Peer review status: This is a non-peer-reviewed preprint submitted to EarthArXiv.

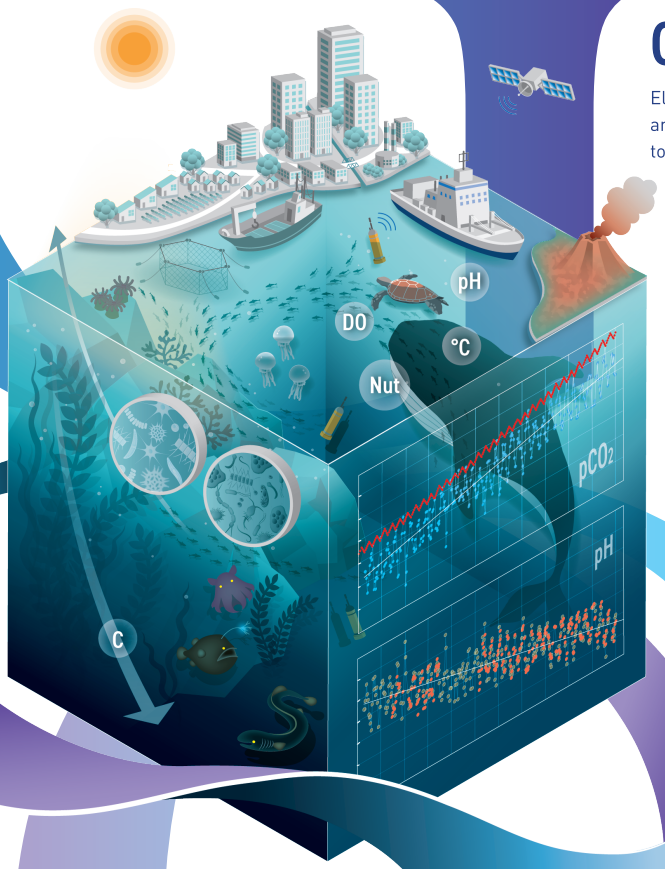
WPI
TOHOKU UNIVERSITY &
JAMSTEC
AIMEC

GC4

Resolving Complexities
in Coastal Marine Ecosystems
and the Impacts of Human Activities

GC1

Elucidating Adaptability
and Vulnerability of Marine Ecosystems
to Physicochemical Drivers



GC3

Coupling of Surface
and Twilight Zone Ecosystems
and the Impact on Biogeochemical Cycles

GC5

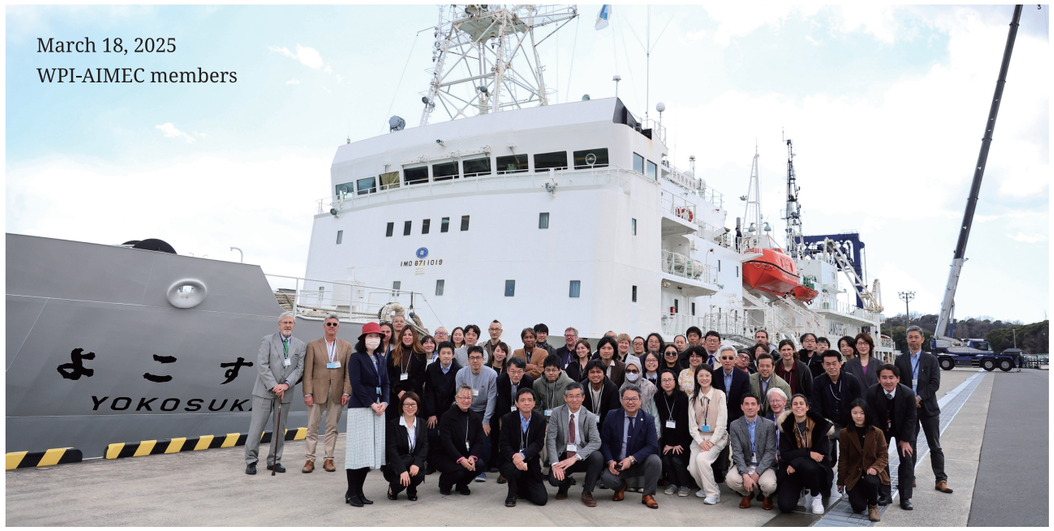
Promoting Planetary Stewardship
through Projection of
Marine Ecosystem Change

GC2

Decoding Climate-Ocean-Ecosystem
Connectivity and
Spatiotemporal Variability

Executive Summary

The Grand Challenges of WPI-AIMEC



WPI-AIMEC members and the research vessel Yokosuka, AIMEC All-Hands Meeting, March 2025, JAMSTEC, Yokosuka, Japan.
Photo : WPI-AIMEC, Tohoku University & JAMSTEC

Understanding and Forecasting Marine Ecosystem Change

The ocean has a heat capacity 1,000 times greater than that of the atmosphere and stores 50 times more carbon comparatively, thus, constituting a major sink of anthropogenically released greenhouse gases. Warming effects of human activities on the climate system are now undeniably shown to impact marine life and ecosystems, both directly via warming of the ocean and/or indirectly altering ocean circulation across spatiotemporal scales. Beyond the effect of warming on individual organisms, a changing climate signal has been argued from modeling studies to cause a ripple effect known as trophic level amplification, resulting in changes in the balance of biomass in different size classes. Larger fractional changes in biomass are expected of predator organisms at higher trophic levels, such as fish, due to shifts in the representative phytoplankton at the base of the food web. With a shift towards smaller phytoplankton, trophic amplification scenarios are expected to disrupt fisheries and carbon storage algorithms and negatively affect ecosystem services necessary for a sustainable society. Despite continued advances in monitoring and modeling of ecosystems projecting changes related to trophic coupling, suitable habitat and biogeochemical element cycling remains difficult due to inadequate information on marine ecosystems across spatiotemporal scales.

WPI-Advanced Institute for Marine Ecosystem Change (WPI-AIMEC) operates based on five institutional Grand Challenges (GCs). These GCs aim to promote fusion science by integrating observational, analytical, and modeling tools to complement theoretical approaches and advance our understanding of the processes driving marine ecosystem change. By combining the research skills and knowledge of the host institutes Tohoku University and Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in partnership with University of Hawai'i, we seek transformative solutions to the grandest challenges of addressing marine ecosystem change through diverse perspectives encompassing marine physics, biology, ecology, biogeochemistry, and data science.

Overall, the AIMEC Grand Challenges offer unprecedented opportunities for cross-disciplinary fusion science and scientific breakthroughs with the attainable goal of "Planetary Stewardship"—the responsible management and care of the natural systems to ensure a sustainable and healthy planet for future generations.

Grand Challenge

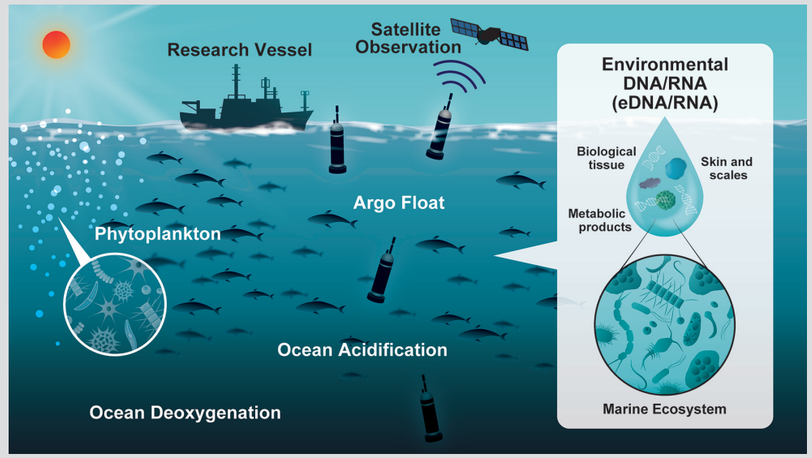
1

Elucidating adaptability and vulnerability of marine ecosystems to physicochemical drivers

Marine Ecosystems are increasingly exposed to a wide range of physicochemical stressors, including ocean warming, acidification, deoxygenation, and nutrient imbalance, which are intensifying under climate change. However, our understanding remains limited regarding how different components of marine life—from microbes to megafauna, intricately linked through ecological interactions—respond to, adapt to, and/or become vulnerable to these multiple stressors.

AIMEC seeks to uncover the biological and ecological mechanisms that govern both adaptability and vulnerability in various levels of marine life. Although our interests are global, initially attention will be devoted to dynamic, transitional ocean regions, such as coastal zones and oceanic fronts, as well as to extreme events such as marine heatwaves—frequently observed in the Northwest Pacific—that may trigger rapid and large-scale ecosystem shifts.

To achieve our goals, AIMEC will integrate diverse observational approaches, such as biogeochemical (BGC) Argo floats equipped with novel sensors, satellite remote sensing, and biodiversity monitoring using environmental DNA (eDNA). By combining these data through mathematical and statistical modeling, AIMEC aims to develop new indicators to assess and predict marine ecosystem response and functional changes. One of our goals is to build a predictive understanding of how marine ecosystems behave under extreme and fluctuating environmental conditions, knowledge that is essential for conserving biodiversity, securing ocean-based livelihoods, and informing nature-positive decision making for a sustainable future.



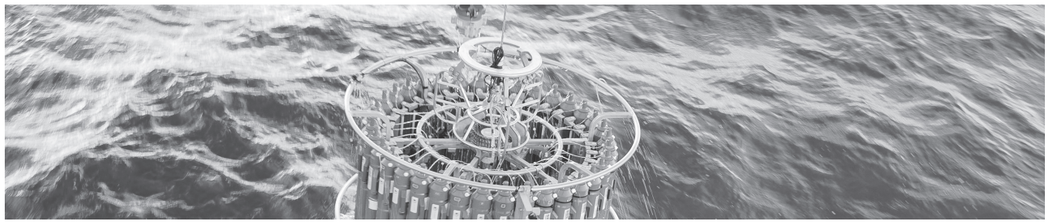
Elucidating the mechanisms of marine ecosystem change requires matching the quality and spatiotemporal coverage of data corresponding to the physics, biogeochemistry, and ecology (Figure from Suga, T., Inagaki, F., Ando, K., and Kotani, M., Science-Policy Brief, UN STI Forum 2023).

SPECIFIC CHALLENGES

- Detecting and interpreting marine habitat shifts and contraction under climate change, using multi-source data including eDNA-based biodiversity signals.
- Elucidating the function and survival strategies of marine ecosystems under ocean acidification and deoxygenation.
- Understanding the impact of marine heat waves on biodiversity structure and marine ecosystem dynamics.

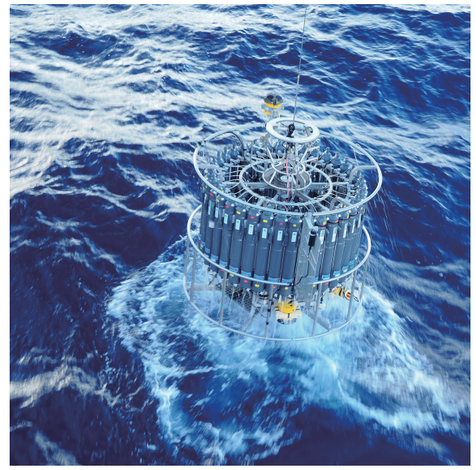
KEY QUESTIONS

- What are the key physical processes affecting marine habitats?
- Can large-scale climate variability or global warming influence marine habitats through not only temperature or stratification changes but also frontal structure changes and meso- or submesoscale activity changes?
- To what extent does the “Climate Velocity” diagnosis work? How can we monitor marine habitat shifts and contraction?
- What are the time scales in marine habitat variability and which mechanism dominate at different scales?
- How can we improve models in predicting the future change of marine habitats?
- What are the extent and consequences of ocean acidification and deoxygenation, especially under global warming?
- How do the different levels of species respond to ocean acidification and deoxygenation?
- How does acidification affect the growth and reproduction of organisms using calcium carbonate and what physiological mechanisms are involved?
- What synergistic effects arise from combining ocean acidification with other environmental factors (e.g., global warming, oxygen depletion)?
- How does deoxygenation affect predator-prey relationships and competition within an ecosystem and how does this impact the ecosystem?
- What are the key drivers of marine heat waves?
- How is the occurrence of marine heat waves impacted by forced changes in the distribution of temperature variability in a transient climate?
- How can we better monitor marine heat waves from the ocean surface down through the water column?
- How can we improve the observation techniques and models to better predict real-time marine heatwaves?
- How do marine ecosystems recover from marine heat waves?
- What are the limits of life and the biosphere? What are the survival and adaptive strategies of marine ecosystems under extreme environmental changes?



APPROACHES

- ✓ Construct an integral observational system by incorporating BGC Argo, satellite, research vessels, continuous seafloor observations at sea bottom (e.g., temperature and pressure measurements), and high-resolution biodiversity monitoring using eDNA. This integrated system will enable integrated assessment of physical, chemical, and biological dynamics from sea surface to bottom.
- ✓ AIMEC leverages ANEMONE—one of the world’s most extensive eDNA monitoring systems—which has accumulated over 8,000 high-resolution eDNA records from repeated surveys at more than 1,000 coastal and inland sites in Japan. These scalable eDNA observations, integrated with physical and chemical data, enable the detection of ecosystem regime shifts and improve model calibration.
- ✓ Establish indicators that can identify areas undergoing significant acidification and deoxygenation, as well as regions where these stressors may trigger broader ecological impacts across connected habitats.
- ✓ Develop high-resolution models to analyze marine heat wave mechanisms under climate change. The application of large ensemble simulations (with high-frequency output) to marine heat waves is necessary not only to represent the statistics of variability but also to facilitate attribution. Robust analysis of marine heat wave evolution under changing climate variability requires large ensemble simulations, ideally with 30 to 100 members, to capture the full range of possible outcomes.
- ✓ By combining biogeochemical modules with future climate scenarios and sensitivity experiments, we can better understand how ocean acidification and deoxygenation vary under global warming. These models can incorporate ecological elements such as food chains and interspecific competition, aiming to explore how marine heat waves, acidification, and deoxygenation affect marine ecosystems—and how these ecosystems, in turn, influence such environmental changes.
- ✓ Apply machine and deep learning to identify relationships between marine heatwaves and large-scale climate patterns (teleconnections). The model will be used to conduct predictive experiments on marine heat wave dynamics under future climate conditions and large-scale climate variability.
- ✓ Conduct detailed examinations of the genetic and physiological traits of species tolerant to acidification and deoxygenation, determining the conditions under which these adaptations have developed. Assess the economic implications of acidification and deoxygenation (e.g., impacts on fisheries and tourism) and recommend measures to control and adapt to acidification and deoxygenation.
- ✓ Design adaptive management strategies, such as redesigning protected areas and establishing fishing regulations, and evaluate the economic impact. Develop resource management plans for specific marine regions to safeguard migrating species. Additionally, assessing the socio-economic impacts of distributional changes on coastal communities and the fisheries sector is critical to ensuring sustainable management practices.



CTD (Conductivity, Temperature, and Depth) water sampling device on RV Mirai. Photo by Masahito Shigemitsu, WPI-AIMEC, JAMSTEC: ©JAMSTEC

2

Decoding climate-ocean-ecosytem connectivity and spatiotemporal variability

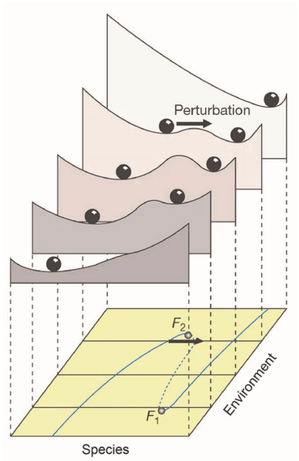
The manifold relationships between physical and ecological processes impact the stability and dynamics of coastal and marine ecosystems under both natural variability and global warming. The spatiotemporal dynamics of coupled physical and ecological systems are expected to determine the trajectory of regime shifts, which are defined as shifts from one relatively stable, persistent state to another.

For example, physical observations have revealed that the Pacific Decadal Oscillation (PDO) and the northward migration of the Kuroshio Extension current drive weather patterns. Furthermore, ecological observations have revealed dramatic and steady changes in the community structure and functioning of marine ecosystems, such as counter-cyclical patterns of anchovy and sardine catches. However, the mechanistic connections between climatic or oceanographic regime shifts and ecological regime shifts remain poorly understood, which limits the ability to forecast ecosystem dynamics and hence the opportunities to develop effective mitigation and adaptation measures.

Advancing understanding of ecological regime shifts in the oceans will require clarifying connectivity within the climate-ocean-ecosystem complex, including nonlinear dynamics and teleconnections. To address this challenge, AIMEC will develop new, integrated approaches that combine advanced time-series analyses, ecological theory, and numerical modeling with extensive and detailed observations of physical oceanography, eDNA, paleoenvironmental records, and others. Ultimately, our goal is to achieve reliable early detection of regime shifts to enhance the ability to mitigate detrimental effects while, in part, adapting despite the consequences.



Water Sampling in progress after CTD retrieval. Photo by Masahito Shigemitsu, WPI-AIMEC, JAMSTEC: ©JAMSTEC



This schematic (modified from Scheffer et al., Nature, 2001) depicts a classic example of regime shifts, invoking a stochastically forced particle in a double-well potential. Each of the potential wells represents a distinct regime, within which the particle fluctuates. Transitions between the wells constitute regime shifts. External forcings may alter the shape of the potential and the properties of the stochastic forcing, which together determine the duration of each regime and the transition likelihood.

SPECIFIC CHALLENGES

- Understanding the relationships between physical and ecological processes and stability (resilience, vulnerability, tipping points) of coastal and marine ecosystems.
- Understanding how spatiotemporal dynamics of physical and ecological systems affect the trajectory of regime shifts.

KEY QUESTIONS

- What are the relationships, including spatiotemporal lags, between the abiotic (physical and chemical) environment and ecological regime shifts?
- How are regime shifts impacted by:
  - heterogeneity in physical, chemical, and ecological variables?
  - ecological connectivity (habitats, populations) and internal ecological dynamics?
  - evolutionary adaptation?
  - the character of marine ecosystems as Complex Adaptive System (CAS)?
- How to detect critical transitions from one regime to another in a generic way under natural variability given the uncertainty of model parameters and their outputs?
- How to identify tipping points for physical and ecological systems?
- How to assess the reversibility or permanence of regime shifts?
- How to disentangle the roles of external (abiotic) drivers and internal ecological dynamics as determinants of the trajectories of ecological regime shifts?
- What new data sources and what levels of complexity should we measure and model to characterize regime shifts?

APPROACHES

✓ Assemble and analyze large, long-term data sets to search for impacts of extreme weather events and known climate oscillations (e.g., El Niño, PDO, NPGO) on ecological regime shifts based on species distributions as observed by eDNA and paleooceanographic proxies for changes in physio-chemical conditions and ocean ecological state.

✓ Combine detailed, cutting-edge observations, advanced modeling and data analyses to understand causal mechanisms of regime shift. For example:
- Extensive local observations and high-resolution modeling of regional water bodies
- Lagrangian views of how organisms experience their environment, as they move with currents and circulation routes
- Observation-based community models to predict species' distributions, interactions, aspects of biodiversity and environmental responses
- Cutting-edge models of physiological acclimation and evolutionary adaptation of key species and communities
- Advanced time-series analyses (e.g., Empirical Dynamic Modeling) applied to both observations and model output
- Large ensemble Earth system model simulations, including perturbed parameter ensembles.

✓ Develop mechanistic understanding of the driving force and potential for physical and ecological regime shifts.

✓ *Long-term objective*: design management schemes that will reduce the likelihood of ecological regime shifts, enhance the resilience of ecosystems or key communities to regime shifts, and reverse undesirable regime shifts.

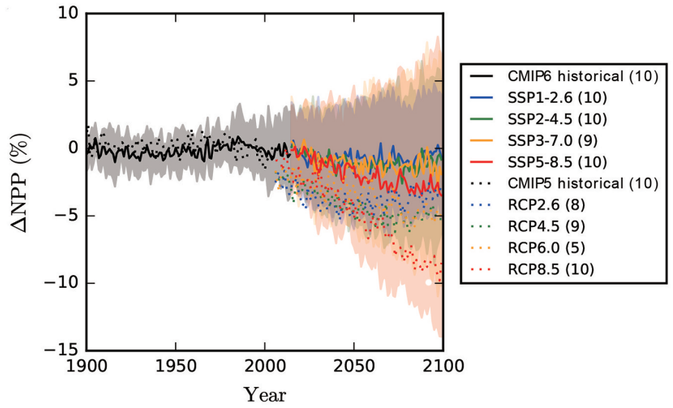
3

Coupling of surface and twilight zone ecosystems and the impact on biogeochemical cycles

The future impacts of climate change on large-scale marine ecosystems remains largely uncertain, reflecting that our understanding of large-scale processes is far from complete. Future upper ocean ecosystem changes are expected to be modulated by interactions between two types of processes exerting bottom-up control on ecosystems.

One being the biological pump, a biogeochemical framework that integrates ecosystem functions across spatiotemporal scales and describes the redistribution of nutrients between the surface layers (where photosynthesis occurs) and the ocean interior. The second being the impact of physical circulation of the ocean, which promotes the upwelling of nutrients to the surface ocean through complex pathways that are challenging to constrain.

AIMEC will leverage its multi-disciplinary strengths in biological and physical oceanography, biogeochemistry and ecology to project interactions between the biological pump and the form of ocean circulation driving future ecosystem changes. We will assess the current climate state through multi-platform observing systems, including BGC Argo floats, which resolve seasonal variations, and will complement these observations with ship-based sampling of marine particles for multi-omics, isotope-geochemistry, and synchrotron-based approaches. A research frontier will be established to understand the role of zooplankton in mediating the exchange of energy between phytoplankton and upper trophic levels, including fish. That process-based understanding will then be used to improve Earth System Models (ESMs) that are used to project future ecosystem changes.



Coupled Model Intercomparison Project (CMIP)-wide uncertainties in primary production (PP) relative to 1870-1899 for projections to 2100 (Figure at left, showing fractional PP changes) over 1900-2100. High emissions (SSP5-8.5) (red line and pink shading are ensemble mean and model structural uncertainty, respectively) highlight challenges in predicting key ecosystem variables over global scales (Kwiatkowski et al., *Biogeosciences*, 2020, Fig. 1 (e)).

SPECIFIC CHALLENGES

- The interplay of biotic and physical processes across spatiotemporal scales that determine carbon fixation at the base of the upper ocean food web is still far from being comprehensively understood. A new framework is needed to understand how these processes will interact to modulate primary production, and interactions with higher trophic levels.
- The collection of biotic processes that determine the functioning of the biological pump are far from being comprehensively understood. Identifying the key processes that regulate remineralization within the twilight zone is particularly challenging, but will be critical to improving process representation in models used to project future ecosystem changes.
- Nutrient limitation (bottom-up) controls on primary production, can be strongly modulated by ocean circulation changes. Additionally, N2-fixation, transport of dissolved organic matter (DOM) from non-local environments, and the microbial loop can be important, and understanding the interplay between these processes is a priority.
- For zooplankton grazing and higher trophic level feeding (top-down) controls on primary productivity, the current observing system is not sufficient to facilitate mechanistic understanding, resulting in highly uncertain model representation. Other drivers such as viruses can also exert top-down pressure on primary production. An expanded observing system is imperative to address these questions regarding zooplankton grazing and higher trophic level feeding.
- Marine ecosystems are understood to exhibit variability across all timescales, and the variability itself should not be assumed to be stationary. Identifying and understanding the variability of ecosystems across timescales is of central importance to the broader set of Grand Challenge goals, and for confidently identifying extreme event evolution.

KEY QUESTIONS

- What are the circulation pathways by which nutrients from the ocean interior are returned to the sunlit surface layers of the ocean, facilitating primary production? What are the respective roles of mixing in the ocean interior and lateral transports?
- What biotic processes in the ocean prescribe the transmission efficiency (vertical structure) of the soft tissue pump? How is it modulated by submesoscale processes? What is the optimal observing system deployment and expansion to deconvolve the processes that contribute to the biological pump, including gravitational sinking and DOM subduction? How can improved process-understanding enhance models?
- What are the temporal scales for marine ecosystem variability, including for cyanobacteria and heterotrophic prokaryotes, primary production and export? How will the intrinsic natural variability present today be impacted by sustained climate change, and by what mechanisms? And how is trophic level coupling (with higher-level trophic level biomass perturbations expected to be larger than phytoplankton biomass) impacted by climate change?
- For detection of anthropogenic changes in primary production against background variability, are nitrogen isotopes in the twilight zone useful? If so, what spatiotemporal sample scale is optimal for trend detection? And are there complementary isotopic approaches that could benefit trend detection?

APPROACHES

- ✓ Expand laboratory experiments and in situ measurements are needed for improved process understanding of not only microbial respiration in remineralization, but also a quantitative assessment of the role of zooplankton flux-feeding. Critical sensitivities to constrain are the controls imposed by temperature and oxygen concentrations, to advance some of the oversimplified parameterizations that are widely used in ESMs.
- ✓ Integrate observations that simultaneously measure microorganisms (prokaryotes, phytoplankton, and micro- and meso-zooplankton), organic matter (dissolved and particulate), temperature, nutrient concentrations, and oxygen levels, can identify remineralization rates and downward organic matter fluxes (export) in three dimensions. Increased process understanding will be of critical value to improving process representation in models.
- ✓ Given the high potential value of using nitrogen and other stable isotopes to investigate anthropogenic transients in primary production, sampling over the North Pacific should be expanded to include repeat measurements, with measurements assessed against model simulations.
- ✓ Comprehensive and systematic process-perturbation experiments with ESMs can be conducted to investigate the role of not only circulation but also ocean interior mixing to assess their role in determining the sensitivity of projections of future ecosystem changes and ecosystem stressor/driver changes. It should also be a priority to move beyond overly simplistic representations of zooplankton functional groups in models.
- ✓ As a complement to observing system expansion, artificial intelligence can be applied to prokaryote zooplankton and zooplankton measurements. This approach will develop mappings to gridded basin-scale products, complementing existing efforts with phytoplankton, and seasonal and interannual variations with increasing data density. The environmental controls on grazing rates can be investigated, with the inferred process understanding applied to improve modeled process representation, given that uncertainties in process representation are currently unacceptably high.
- ✓ Large ensemble simulations with an eddy-permitting ESM will be a critical tool for identifying how anthropogenic forces change the natural variability of marine ecosystems, as well as for evaluating climate change.



Scanning electron microscopy (SEM) image of *Podomonas kaiyoae*, a novel apusomonad. Photo by Akinori Yabuki, WPI-AIMEC, JAMSTEC

4

Resolving complexities in coastal marine ecosystems and the impacts of human activities

Interconnections between socio-ecological interactions and oceanographic processes in coastal regions are among the most complex global systems. However, teasing apart the intricacies of the multifaceted networks require cross- and trans-disciplinary efforts for assessing ecological health, connectivity between land and sea, and potential threats to marine ecosystems at a range of spatiotemporal scales.

Addressing these complexities, AIMEC will evaluate the transitional patterns of ecosystem structure and functioning from the coast to the open ocean using state-of-the-art observational and experimental approaches. We aim to quantify the cumulative impacts of multiple anthropogenic stressors on coastal ecosystems, using big-data to identify specific reciprocal relationships and spatiotemporal scales at which effects can be measured.

Specifically, Onagawa Bay and Mutsu Bay, representing unique oceanographic and anthropological settings, will be selected as model coastal areas to investigate the regulatory functions and societal benefits of the marine ecosystems. Quantitative analyses will expose their capacity to deliver ecosystem services, such as nutrient cycling, carbon sequestration, and marine resource provisioning (i.e., fisheries and aquaculture). Focus will also be placed on exploring the land-to-sea interactions in the context of extreme weather events (e.g., typhoons, torrential rains), and the functionally adaptive role of ecosystems in the dispersal and degradation of materials generated by human activities, such as microplastics.



Oyster farming in Shizugawa Bay. Photo by Takashi Sakamaki WPI-AIMEC, Tohoku University



Surveying seagrass meadows in Onagawa Bay. Photo by Toyonobu Fujii, WPI-AIMEC, Tohoku University

SPECIFIC CHALLENGES

- Exploring ecosystem transitions across coastal and oceanic regions: Measure the structure and function of marine ecosystems in terms of biodiversity, distribution, and genomic composition for assessing their geographic and bathymetric transitional patterns in relation to various biotic and abiotic factors across a range of spatial and temporal scales.
- Quantifying the impact of human activities on marine ecosystems: Identify the types and dynamics of human activities operating in the marine environment. Quantify their impact on ecosystems across coastal and oceanic regions.
- Developing scientific strategies to confront multiple anthropogenic stressors: Science-based management strategies aimed at minimizing the cumulative impacts of anthropogenic stressors on marine ecosystems to form the basis for conserving marine ecosystems and implementing sustainable resource management.
- Transforming ecosystem services into a blue economy: Assess the structure and functioning of marine ecosystems in relation to the provision of ecosystem services. This can provide a basis for conservation, spatial planning and decision making for marine and coastal management as well as for the transformation of ecosystem services into blue economy.

KEY QUESTIONS

- How is the health and/or the integrity of the oceans related to the structure and function of the marine ecosystems?
- How do anthropogenic factors affect marine communities across coastal and oceanic regions?
- What are the significant factors leading to changes in marine biodiversity across coastal and oceanic regions?
- What are the responses and adaptive mechanisms of marine life to human-induced environmental changes?
- How can we assess the responses of marine ecosystems to the cumulative impacts of multiple anthropogenic stressors?
- What fisheries resources or habitat types might be resilient, and what are the physiological, genetic, environmental mechanisms underlying such resilience?
- What are the impacts of human activities and/or biodiversity loss on marine ecosystem services? What are the impacts of losing a specific group of organisms or habitats to human society?
- How can we make ecosystem services suitable for promoting blue economy?



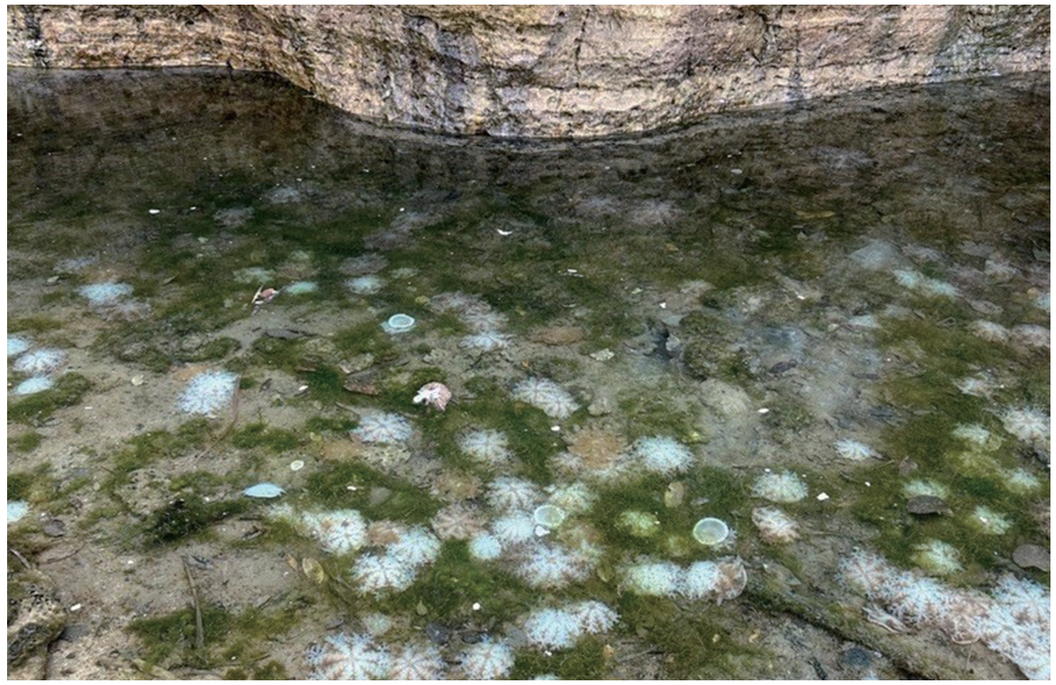
Harmful Argal Blooms (red). Photo by Lael Wakamatsu, WPI-AIMEC, JAMSTEC



Surveying seawater conditions in Ishinomaki Bay using a CTD profiler. Photo by Toyonobu Fujii, WPI-AIMEC, Tohoku University

APPROACHES

- ✓ Long-term monitoring will be conducted to collect data on the distribution of targeted marine organisms and associated environmental variables. This is especially crucial for key fishery resources and species critical to the ecosystem as it is necessary to understand any changes in their abundances and migration patterns.
- ✓ Conduct studies to identify what types of human influences exist in the marine environment and quantify the impact of the respective human activities on marine ecosystems with a special focus on high-impact areas and species.
- ✓ Explore how multiple anthropogenic stressors interact under controlled experimental conditions, enhancing our understanding of their combined effects on marine ecosystems. Under various cumulative scenarios, ecosystem models will be created to simulate their collective impact and shifts in ecosystem structure and functioning.
- ✓ An evaluation of ecosystem trends and variability will be performed under the influence of multiple anthropogenic stressors expressed as a signal-to-noise ratio at varying timescales across coastal and oceanic regions to detect broader question of ecosystem vulnerabilities.
- ✓ Assess both economic and biophysical impacts of human activities on ecosystem services to provide scientific data that both economically and ecologically demonstrate the need for protection. This will aim to influence policy recommendations and resource allocation for a blue economy, design flexible conservation strategies, and develop resource management plans for specific marine regions to safeguard biodiversity hotspots.



Bleached “upside-down jellyfish” in Okinawa. Photo by Cheryl Ames, WPI-AIMEC, Tohoku University

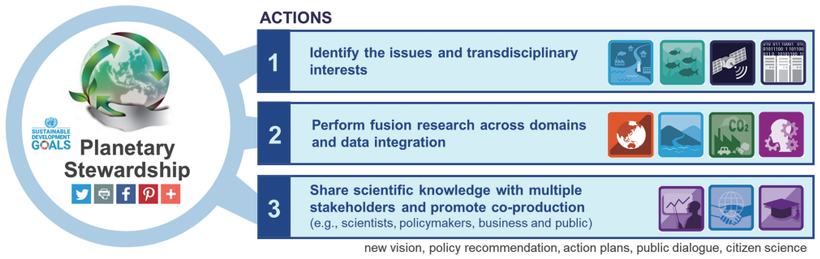
5

Promoting planetary stewardship through projection of marine ecosystem change

To make sophisticated ecosystem projections, AIMEC will establish an advanced ESM using various technological developments, including satellite and sea surface observations and artificial intelligence (AI)-based techniques. These advances will be coupled with the accumulation of scientific knowledge delivered from GC1 through GC4. Emphasis will be placed on improving the representation of marine ecosystems with the latest accomplishments of international observational efforts, such as “OneArgo” and “ANEMONE Global”.

The AIMEC research program is sure to have a profound impact on policy-making when findings are disseminated to stakeholders, including private industries, local governments, and international organizations (e.g., IPCC, UNESCO-IOC, and IPBES). Sharing these insights with the public will contribute to the development of global policies and norms related to climate-ocean-ecosystem change, marine conservation and restoration, and the achievement of the Sustainable Development Goals (SDGs).

By adopting a transdisciplinary approach in which stakeholders are involved in the issue identification stage, possibly mediated by Science-Policy-Society Interfaces (SPSIs), AIMEC aims to expand scientific knowledge base for understanding marine ecosystem variability and changes, thereby, enhancing its credibility and social value. Engaging with stakeholders to co-create solutions to these grand challenges, AIMEC will transform scientific findings into actionable knowledge for the general public to promote “Planetary Stewardship” towards the sustainable management of the ocean, the Earth, and human society.



Conceptual chart of knowledge co-production by scientific communities and the society. To effectively steward the planet, particularly marine environment and its ecosystems, transdisciplinary research must integrate knowledge from natural sciences, social sciences, economics, policy, and local communities. This holistic approach helps address the AIMEC Grand Challenges related to climate change.

SPECIFIC CHALLENGES

- Identifying uncertainties in future projections (i.e., spatial uncertainties of, e.g., climate change and species distribution predictions [range shifts], quantitative uncertainties of temperature change and species abundance projections, etc.).
- Significant uncertainties in projected climate change and its impacts on society have been hindering governments from taking political measures.
- Reducing the gap between scientific knowledge and social implementation.
- Quantifying changes in environment and ecosystem services to the human society.
- Mobilizing the interest of diverse stakeholders.

KEY QUESTIONS

- What is planetary stewardship? What are the steps to achieve it?
- If planetary stewardship means Earth system management in any way, is it ever possible to “manage” the Earth system?
- How can knowledge on oceanography contribute to mitigation and adaptation against global change, and in turn realizing a sustainable society?
- How should we visualize scientific results and communicate them with uncertainties to the public?
- How can we quantify and map the services nature provides us to enhance public awareness?
- How can scientists contribute to policy-making addressing global change?
- Should stakeholders be involved to frame problems with scientists in a way that interests both parties? If so, how?

APPROACHES

- ✓ Sharing the concept of uncertainty and scientific knowledge through active outreach and dialogue with the public.
- ✓ Involvement in activities such as IPCC and IPBES in the international community, and through international research cooperation.
- ✓ A novel international cooperation framework aiming at promoting sustainability.
- ✓ Capacity building of experts and education for students in marine ecosystems and global environment with an international perspective.
- ✓ Two-way communication with stakeholders: to incorporate into our research the opinions and values of the society (residents and fishers in coastal areas) about how they value ecosystem services and the associated risks to the societal and environmental sustainability.



Crowd of reef fish. Photo by Kota Ishikawa, WPI-AIMEC, Tohoku University

WPI
TOHOKU UNIVERSITY &
JAMSTEC
AIMEC

Advanced Institute for Marine Ecosystem Change
(WPI-AIMEC), Tohoku University and Japan Agency for
Marine-Earth Science and Technology (JAMSTEC)

6-3, Aramaki Aza-Aoba, Aoba-ku, Sendai 980-8578, Japan
Mail: aimec-contact@grp.tohoku.ac.jp

wpi

TOHOKU
UNIVERSITY

JAMSTEC