Using the COHERENS model scenarios to safeguard Ha Long Bay waters

Recommendations for water quality, resilience and sustainable management

KEY-MESSAGES

1

COHERENS[1] is a flexible open-source marine model that simulates the tides, currents, water temperature, salinity and ecological processes and produces data that can't otherwise be collected in a cost-efficient way.

2

It is now possible to assess the combined impact of future scenarios on water quality:
1. Impact of climate change through temperature variation and sea level rise
2. Impact of human activities (like increased pollution, land reclamation etc.) that influences water quality.

3

Scientists and policy-makers can now work together to determine water quality indicators, and select and implement scenarios to improve water quality in Ha Long Bay based on the indicators.

Context

Ha Long Bay became one of the new 7 Natural Wonders of the World and was twice recognized by UNESCO[2] as a World Natural Heritage Site. This unique archipelago of 1969 islands is home to birds, coral reefs, marine animals, mangrove and forest.

Property managers and tourism operators have exploited these potentials to attract investment and develop tourism and industry, despite of environmental impacts, allowing the building of hotels, opening many new tourist routes on the bay, building coastal structures etc. Tourism has been booming from 1.6 million visitors in 2010 to 6.8 million in 2023.

Hence, the marine environment of Ha Long Bay is being put under pressure by the growing flow of industrial, domestic and agricultural waste. At present, water samples show evidence of hydrocarbon and coliform pollution, as well as other pollutants, such as heavy metals, chlorinated pesticides and organic matter. This worsening water quality and pollution is massively recognised, first by UN[3] and UNESCO, but also by scientific literature, traveller's blogs, IUCN[4], NGO's[5] and media.

Through its ability to assess the impact of scenarios, **COHERENS** can play a decisive role in this problem.

The COHERENS model for scientists and policymakers

COHERENS is a flexible open-source hydrodynamic ecological marine model that provides a detailed picture of marine dynamics, making it a valuable tool for testing hypotheses and scenarios (Figure 1). Thanks to the variety and quality of simulated processes and variables, it helps researchers understand complex interactions within environment and ecosystems.

One of the key advantages of COHERENS is its ability to generate extensive geographical data that would otherwise be too costly to collect. By simulating large-scale marine environments, the model provides crucial insights while significantly reducing research costs. This makes it an efficient solution for environmental studies and management.

Website:
https://ecomod-rbins.github.io/website/posts/projects/COHERENS

The model is continuously evolving. Recent improvements include the integration of biogeochemical components, such as nutrients, phytoplankton, and oxygen, which are essential for representing the Ha Long Bay food chain. Comparisons with in situ observations confirm that COHERENS successfully captures the seasonal cycle, and with further calibration, its accuracy could be further enhanced.

As the project progresses, COHERENS is now capable of assessing the impact of anthropogenic activities and climate change on Ha Long Bay's water quality. To ensure long-term benefits, environmental managers were trained to use the model in June 2023 and January 2024 (Figures 3 & 4). This initiative supports continuous scientific advancements and promotes informed decision-making by policymakers, who play a crucial role in preserving Ha Long Bay's ecosystem.

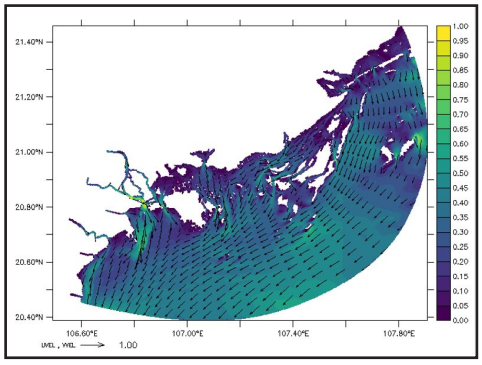


Figure 1. *COHERENS model in Ha Long Bay, showing surface currents (arrows) and current speed (colors, m/s), which vary over time.*

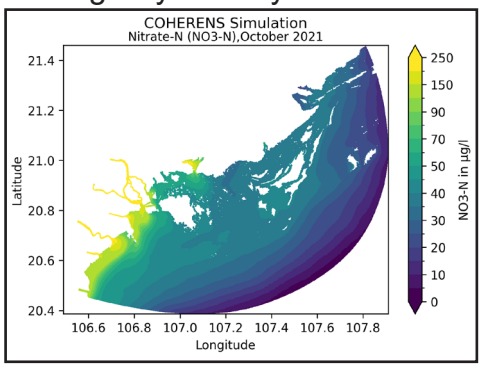
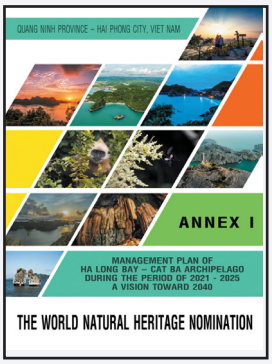


Figure 2. *COHERENS model in Ha Long Bay, showing nitrate levels (colors) to assess water quality, which varies over time.*

During a workshop organised by IMER[9] and RBINS[10] in 2015 in Hai Phong, Vietnam, the participants identified eight main causes of the degradation of the Ha Long Bay ecosystem:

1. **Habitat destruction** (deforestation, dredging, dumping, coastal urbanisation),
2. **Oil pollution**,
3. **Eutrophication** (aquaculture, agriculture, tourism, industry),
4. **Industrial continuous pollution,**
5. **Lack of integrated management,**
6. **No enforcement of management**,
7. **Natural hazards**
8. **Depletion of natural resources** (overfishing).

At that time already, it became clear that cooperation with the managers and administrators of Ha Long Bay, as well as policymakers, has a crucial place.



Ever since, the "Management Plan Of Ha Long Bay - Cat Ba Archipelago" for 2021-2025 has been released by Quang Ninh Province & Hai Phong City authorities, including a vision towards 2040. This document can serve as a basis for future advocacy on water quality in Ha Long Bay, as it contains information and adopted measures that play a crucial role, both for and against, in the coming years for the industrial development of the site. A better consideration of scientific results and studies on the Ha Long Bay, and possible COHERENS-based scenarios, would be appreciated in next management plan.

Figure 3. Prof. Dr. Nguyen Van Quan, IMER Director, addressing scientists and Ha Long Bay Environmental Managers in 2024.

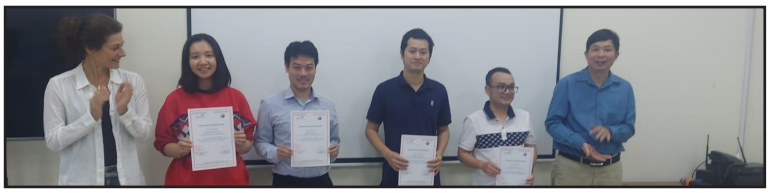


Figure 4. Prof. Dr. Nguyen Van Quan, IMER Director, and Dr. Geneviève Lacroix, ECOMOD[11] team Coordinator, handing out training certificates in 2024.

Scenario results

Based on the supplementary survey (2021) and data collected, the impact of seven scenarios on water quality was tested using the COHERENS model, covering climate change, human activities (pollution), and their combined effects. These scenarios, projecting conditions for the present, for 2030, 2050, and 2100, integrate rising temperatures, sea level rise, and increased nutrient pollution from rivers, aiming to understand the intertwined impacts of natural and human pressures on the bay's ecosystem.

The simulations reveal significant seasonal variations in key environmental parameters. Rising water temperatures across all scenarios are particularly concerning, as they can disrupt marine biodiversity, alter reproductive cycles, and shift species distributions. Additionally, higher temperatures can increase the rate of oxygen consumption in the water, leading to decreased dissolved oxygen levels during peak summer months, which stresses aquatic life.

Sea level rise is another critical factor. Scenarios project noticeable increases in water levels — up to 72 cm by 2100. This rise could lead to coastal erosion, saltwater intrusion, and changes in salinity, especially during dry seasons when freshwater decrease. These shifts could disrupt the bay's delicate balance, affecting both marine life and the livelihoods of local communities. While nutrient concentrations such as nitrate and ammonium do show increases, particularly under human activity scenarios, it's clear that the broader challenge lies in managing the combined effects of climate change and human activities. Elevated nutrient levels contribute to algal blooms, but it's the combination with rising temperatures and altered water flows that creates a complex threat to water quality and ecosystem health.

To address these challenges, comprehensive management strategies are essential. This includes not only controlling pollution sources, like agricultural runoff and wastewater, but also enhancing climate resilience through measures such as habitat restoration and adaptive infrastructure planning. Strengthening monitoring systems will also be crucial, allowing for real-time data collection and responsive management actions.

Overall, the findings highlight the urgent need for coordinated action among policymakers, scientists, and local communities. By addressing both climate impacts and human-induced pressures, it's possible to develop adaptive strategies that safeguard Ha Long Bay's ecosystem and ensure its sustainability for future generations.

Year	Changes			
2030	+0,9°C	+13cm		
2030				NO_3 +38.3% NH_4 +41.4% PO_4 +79.4%
2030	+0,9°C	+13cm		NO_3 +38.3% NH_4 +41.4% PO_4 +79.4%
2050	+2°C	+26cm		
2050	+2°C	+26cm		NO_3 +38.3% NH_4 +41.4% PO_4 +79.4%
2100	+3,5°C	+72cm		
2100	+3,5°C	+72cm		NO_3 +38.3% NH_4 +41.4% PO_4 +79.4%

Table 1 *Representative scenarios of human impacts and climate change were established based on the expected increase in pollutant sources (NO_3, NH_4, PO_4) due to socio-economic activities (tourism, aquaculture, daily life, industry, agriculture...) and climate change scenarios in Vietnam, provided by the Ministry of Natural Resources and Environment.*

Temperature

Sea Level Rise

Pollution

Policy Recommendations

The **COHERENS** model should serve as a **reference for future decision-making** regarding water quality in Ha Long Bay, enabling the selection and implementation of **COHERENS**-based **scenarios** that will allow for improved water quality in Ha Long Bay

Policymakers and authorities can now determine a set of **water quality indicators**, along with scientists, that will allow them to monitor these scenarios.

Nutrient pollution should be reduced to improve water quality, by **strengthening wastewater treatment regulations** for industries and urban areas, and increasing monitoring of river nutrient loads ensuring proper filtration of nutrients before discharge into Ha Long Bay.

Stricter land-use planning should be implemented in low-lying coastal areas to minimise the impact of rising sea levels and prevent uncontrolled urban expansion. In this context, enhancing **mangrove reforestation** along the coastlines is very effective to reduce erosion, provide natural flood barriers, and improve biodiversity resilience.

Education campaigns for fishermen, farmers, and businesses should be launched to raise awareness on the risks posed by climate change and pollution, also providing financial and technical support for eco-friendly livelihoods.

Representation and translation of scientific results along with **COHERENS**-based scenarios should be increased in **future Management Plans of Ha Long Bay**.

Acronyms:
1 COHERENS - COupled Hydrodynamical Ecological model for REgioNal Shelf seas
2 UNESCO - United Nations Educational, Scientific and Cultural Organisation
3 UN - United Nations
4 IUCN - International Union for the Conservation of Nature
5 NGO - Non-Governmental Organisation
6 CLIMDIS - Management of the water quality in Vietnamese coastal waters impacted by CLIMate change and human induced DISasters using a marine modelling tool
7 BELSPO - Belgian Science Policy Office
8 MOST - Ministry of Science and technology of Vietnam
9 IMER - Institute of marine environment and resources
10 RBINS - Royal Belgian Institute for Natural Sciences
11 ECOMOD - Ecosystem Modelling

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Contact:
Institute of marine environment and resources (IMER)
Vu Duy Vinh | vinhimer@gmail.com
Nguyen Minh Hai | hainm85@gmail.com
Institute of Natural Sciences
Geneviève Lacroix | glacroix@naturalsciences.be

Sources:
Geneviève Lacroix, Vu Duy Vinh, Nguyen Minh Hai, Saheed Puthan Purayil, Hugo Romanelli, Arthur Capet. Management of the water quality in Vietnamese coastal waters impacted by CLIMate change and human induces DISasters using a marine modelling tool (CLIMDIS). Final Report. Brussels: Belgian Science Policy Office 2024 – 86 p. – BELSPO, International research cooperation.

Nguyen Minh, H., Ouillon, S., Vu Duy, V. (2022). Sea-level rise in Hai Phong coastal area (Vietnam) and its response to enso - evidence from tide gauge measurement of 1960-2020. Vietnam Journal of Earth Sciences, 44(1), 109–126.

Vu Duy, V., Ouillon, S., Nguyen Minh, H. (2022). Sea surface temperature trend analysis by Mann-Kendall test and sen's slope estimator: a study of the Hai Phong coastal area (Vietnam) for the period 1995-2020. Vietnam Journal of Earth Sciences, 44(1), 72–91

Nguyen, Hai M., Sylvain Ouillon, Vinh D. Vu. (2022). Sea Level Variation and Trend Analysis by Comparing Mann–Kendall Test and Innovative Trend Analysis in Front of the Red River Delta, Vietnam (1961–2022), Water 2022, 14(11), 1709.

Vinh Duy Vu, Hai Minh Nguyen, Saheed Puthan Purayil, Geneviève Lacroix, Duong Thanh Nguyen (2024). Seasonal variation of hydrodynamics in the Cat Ba - Ha Long coastal area (Viet Nam): Results of COHERENS Model. Regional Studies in Marine Science, 80:103874. https://doi.org/10.1016/j.rsma.2024.103874

Authors:

Nguyen Minh Hai & Vu Duy Vinh, Institute of marine environment and resources (IMER), Vietnam
Arthur Capet, Hugo Romanelli, Geneviève Lacroix & Saheed Puthan Purayil, ECOMOD, Institute of Natural Sciences, Belgium
Pierre Huybrechts, CEBioS, Institute of Natural Sciences, Belgium