ASSESSMENT OF ECOSYSTEM RESPONSE TO WATER QUALITY CHANGE USING MEC MODEL COMBINED WITH COMPETITION MODEL IN PUJADA BAY, PHILIPPINES

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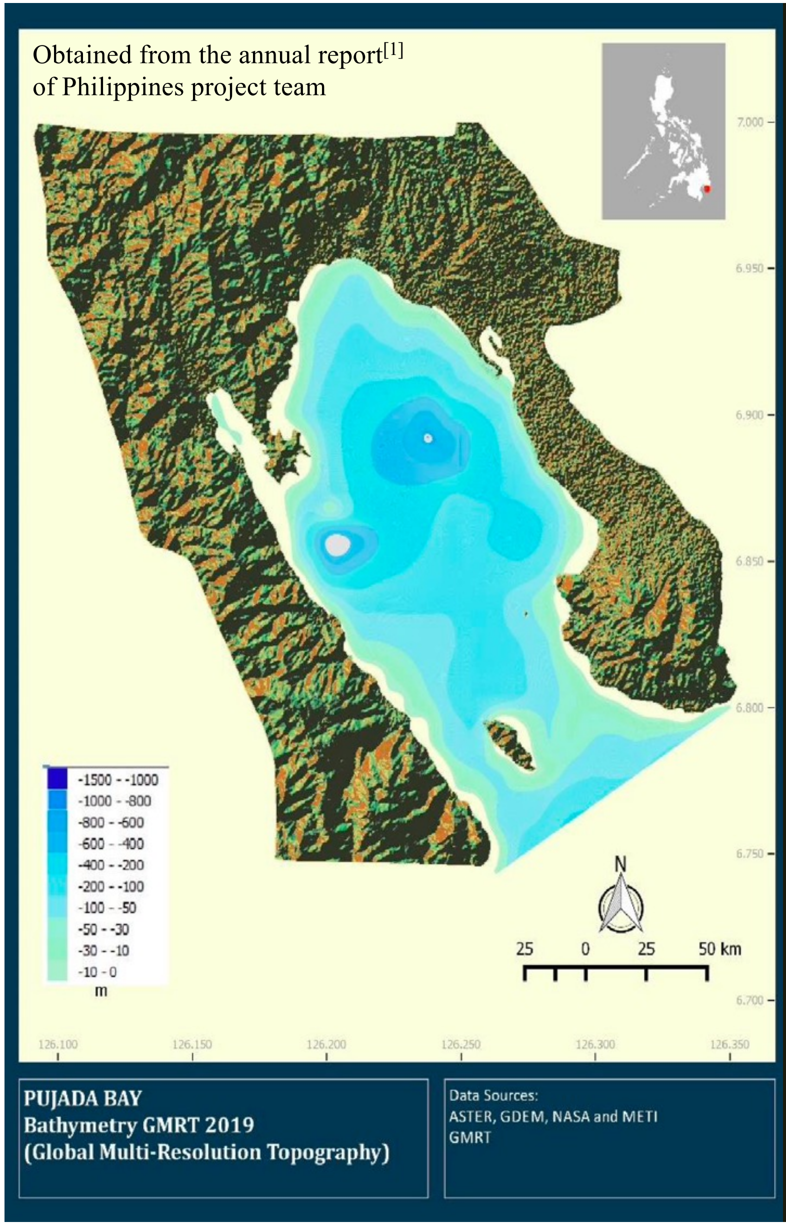


Obtained from the annual report[1] of Philippines project team

Background

- Project Title:
  Development of a Comprehensive Coastal Ecosystem Modelling, Mapping and Monitoring Systems (CCEMMMS)

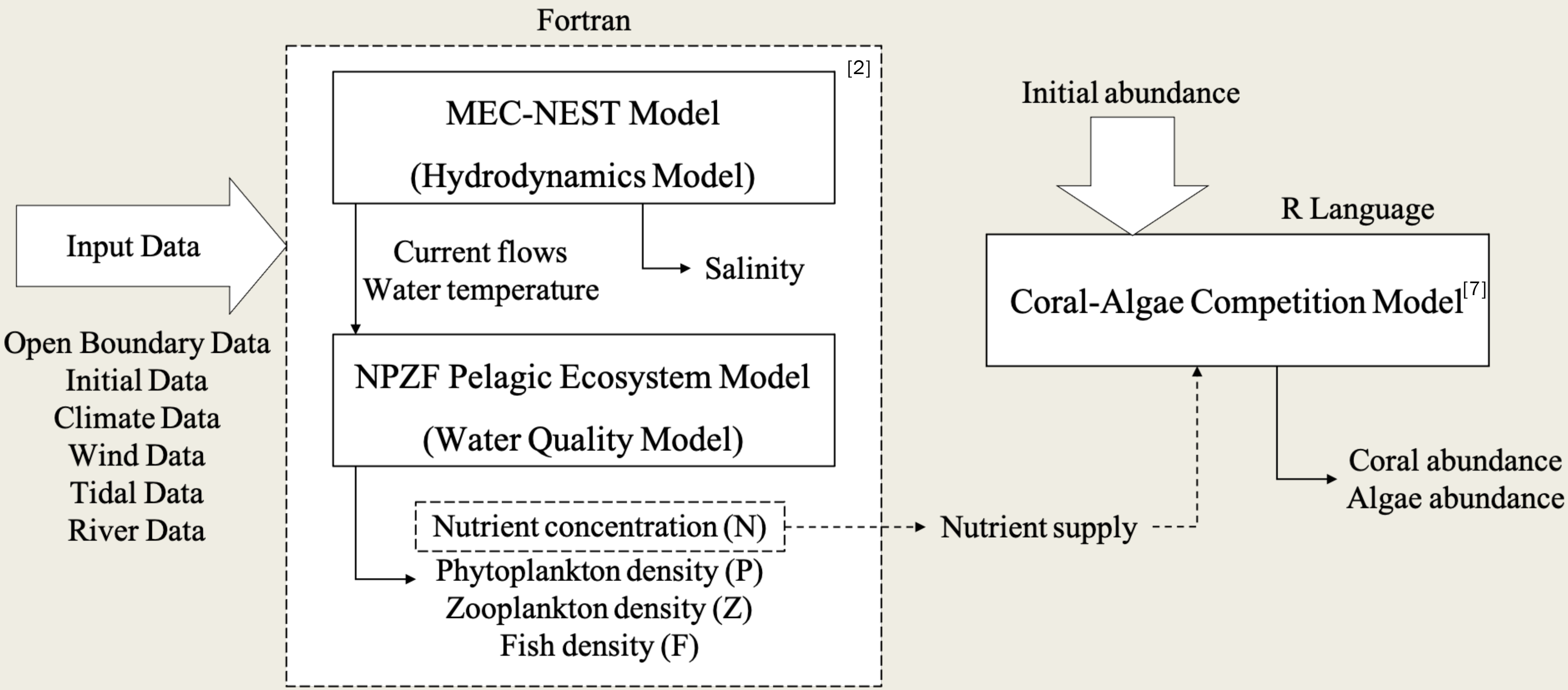
- Project Concerns:
  Coastal population growth and impact on ecosystem.
  Coral-algae habitat and impact on tourism.

- Project Objective:
  Future prediction and determination of critical environmental factors on the marine ecosystems through computational ecosystem-based Modeling

Research Objectives

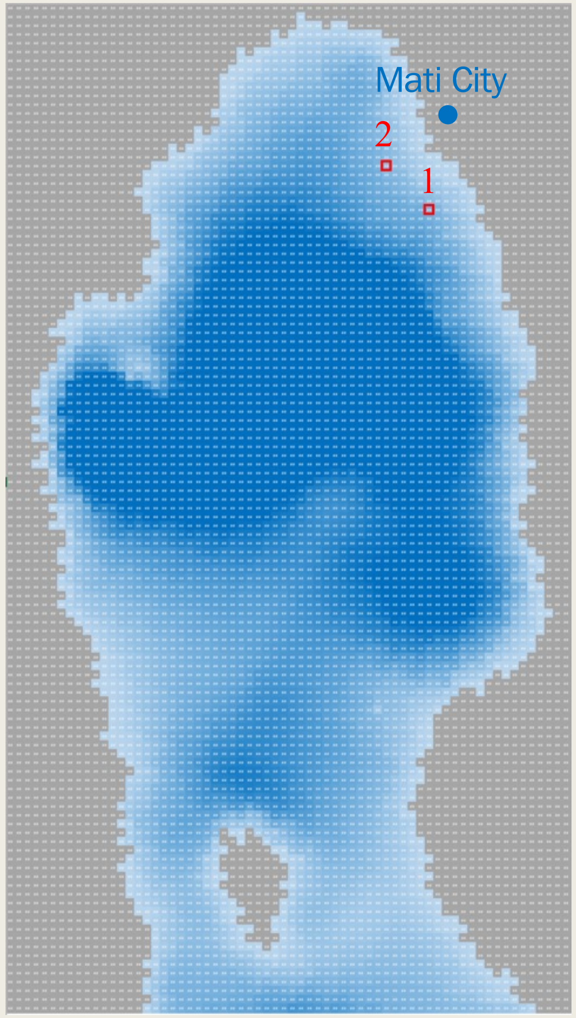
- Collection and modification of relevant input data.
- Conduct numerical simulations in Pujada Bay during certain time period to reproduce the environment.
- Introduce a coral-algae competition sub model to the water quality model.
- Based on the result of coupled model simulation, establish a rational link between human activities, water quality changes and ecosystem changes.

Structure of Models Used



Simulation Condition

- Simulation area is the rectangle range between 6.74~6.98°N and 126.14~126.35°E, with 30-degree rotation. (13km×23km)
- The only open boundary is located at the lower side of this area.
- Divided into 200m-size meshes (66×115)
- Divided into 31 layers
- Two points near the biggest city were selected as the output points of the simulation results
- One month-long simulation (July & September)



Open Boundary Data & Initial Data

- For these input data, the observation data from an out-of-bay observation site are used because it is the nearest site from the open sea.
- Input data of zooplankton was based on the ratio of the surface layer to phytoplankton to determine the value of full depth since there was no direct data for the deep layer.

Parameter	Unit	July			September		
		Surface (2m)	Medium (150m)	Bottom (300m)	Surface (2m)	Medium (150m)	Bottom (300m)
Temperature	℃	30.1482	28.0490	9.6544	30.6126	28.8203	9.4948
Salinity	psu	34.1044	34.5027	34.2799	34.2799	34.6278	34.3410
Phytoplankton	mmol-N/m^3	0.3360	0.1670	0.0075	0.3366	0.1488	0.0064
Zooplankton	mmol-N/m^3	0.0114	0.0056	0.0003	0.0114	0.0050	0.0002
Nutrient	mmol-N/m^3	0.0821	0.0063	19.2773	0.0469	0.0067	22.8408
Fish density	mmol-N/m^3	0	0	0	0	0	0

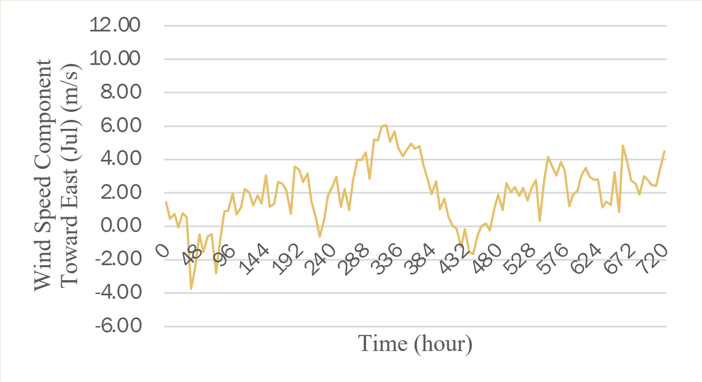
(Refer to CMEMS[3])

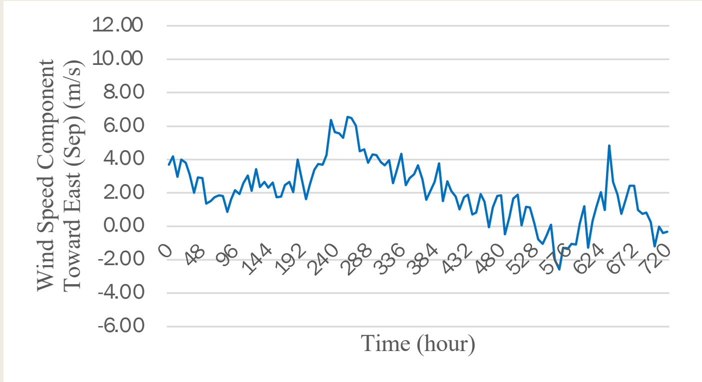
Climate Data

- The various climate data were mainly obtained from Solcast and PAGASA.

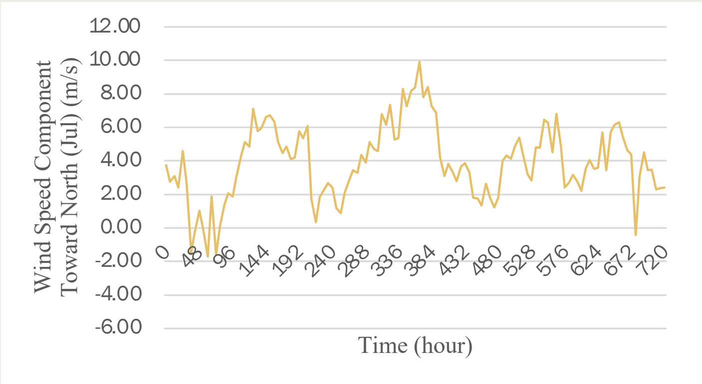
Data Type	Unit	Source
Atmospheric Temperature	℃	
Atmospheric Pressure	hPa	
Global Solar Radiation	J/m^2 /s	Solcast[4]
Cloud Amount	-	
Relative Humidity	-	
Precipitation	mm/s	PAGASA[5]

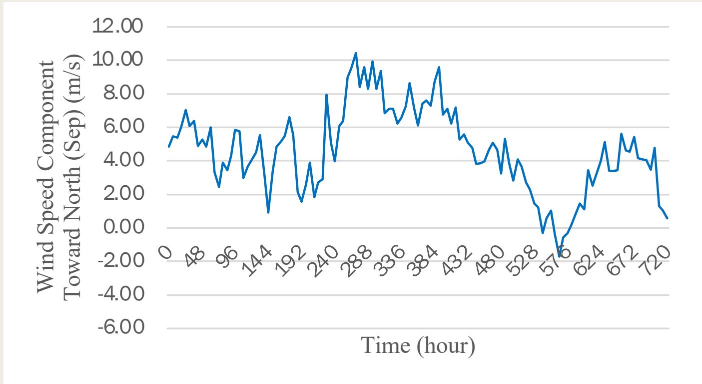
- It should be noted that only the daily total rainfall was available for the precipitation data, so the precipitation per second input here was based on the daily total rainfall by converting them into average distribution over certain hours.





Refer to CMEMS[3]





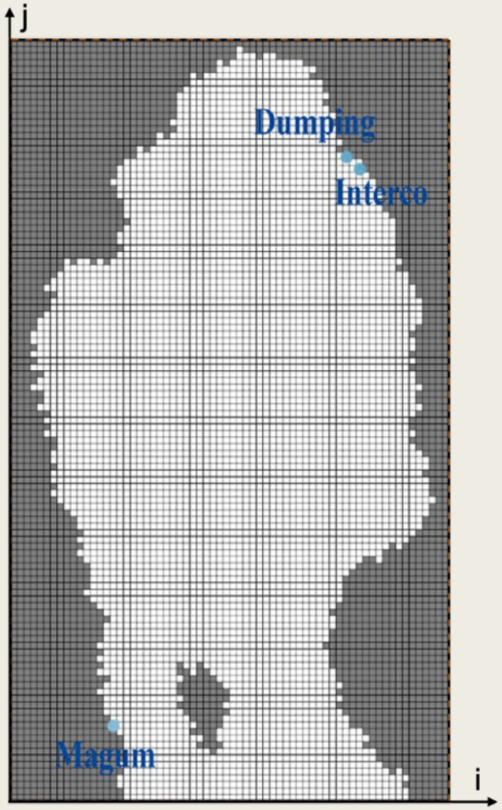
Refer to CMEMS[3]

The information of tide at Mati

Location	Constituent	Symbol	Period (s)	Amplitude (m)
MATI, Davao Oriental (06°57′N, 126°13′E)	Principal Lunar Semi-Diurnal Tide	M2	44714.164	1.30

Calculated from observed tidal data of TIDES4FISHING[6]

River Data

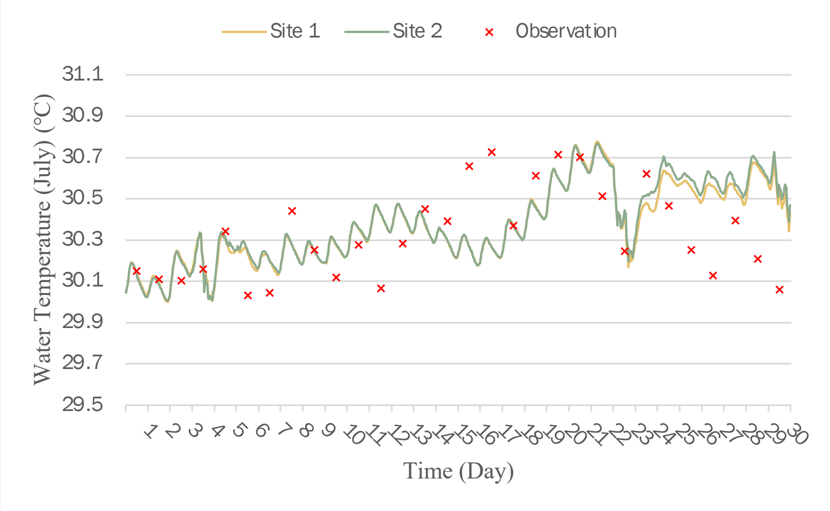


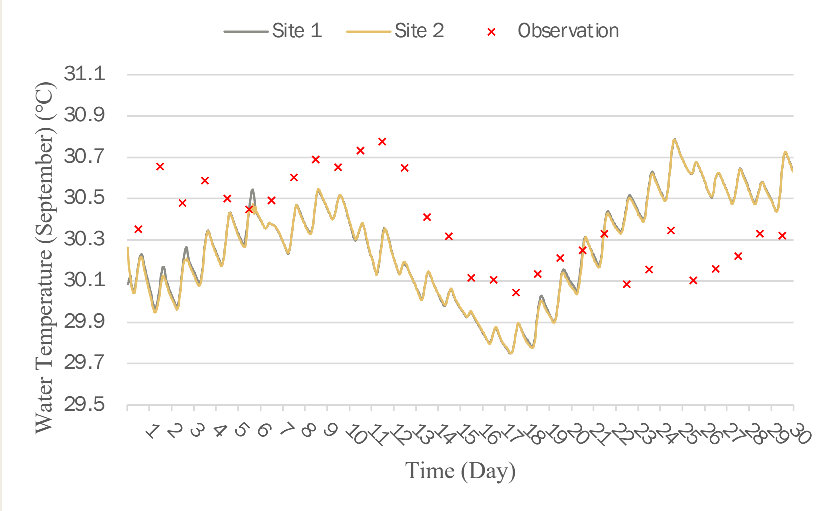
- There are three rivers that flow into the bay.
- The grid map shows the inlets of three rivers.

River	Magum River (Magum)		Matiao Creek (Interco)		Pahamutang Creek (Dumping)	
Parameter	July	September	July	September	July	September
Discharge (m^3/s)	0.33	0.11	0.09	0.03	0.09	0.03
Temperature (℃)	23.74		27.47		28.97	
Salinity (psu)	0.14		0.34		4.69	
Phytoplankton (mmol-N/m^3)	0.3366		0.3366		0.3366	
Zooplankton (mmol-N/m^3)	0.0114		0.0114		0.0114	
Nutrient (mmol-N/m^3)	0.1435		0.1435		0.1435	

Provided by Philippines project team (only for September 2020)

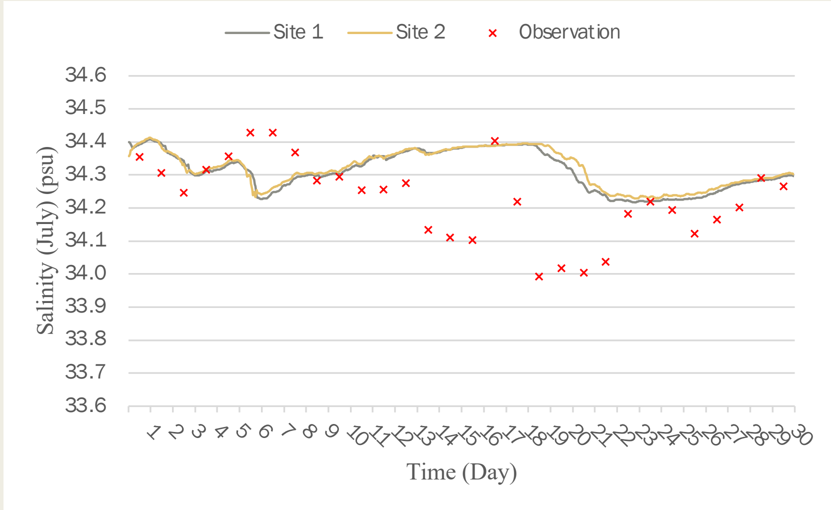
Time series of the water temperature at surface





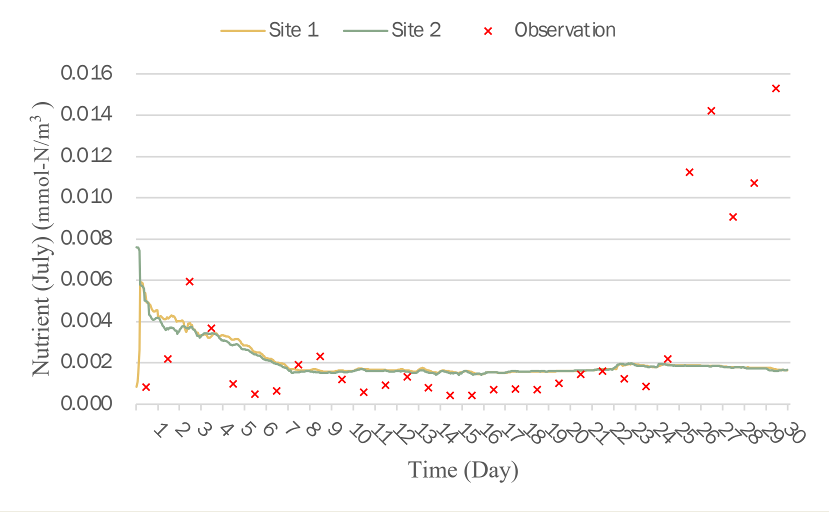
- Simulated water temperature reproduced the diurnal fluctuation tendency but remained difference between the time variations.
- The fluctuation of the simulation results for both months were within reasonable values.
- possible reasons for errors:
  1) wind pressure or sudden short-lived rainfall; 2) the screening effect of aquatic organisms; 3) simulation approximations

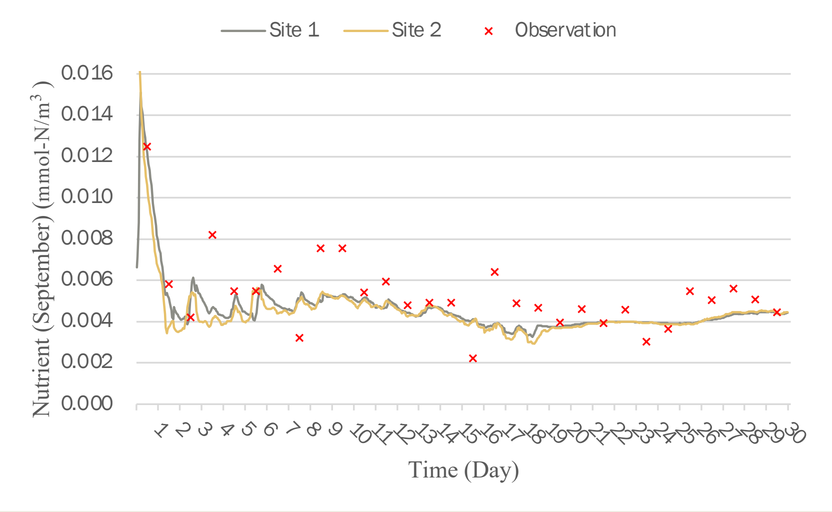
Time series of the water salinity at surface



- Simulation of July did not show a decreasing trend, but two sudden salinity dips on the 4th day and 23rd day.
  This phenomenon can be attributed mainly to the precipitation in the climate data.
- Simulation of September performed better than July, which can be explained by the less rainfall in September.

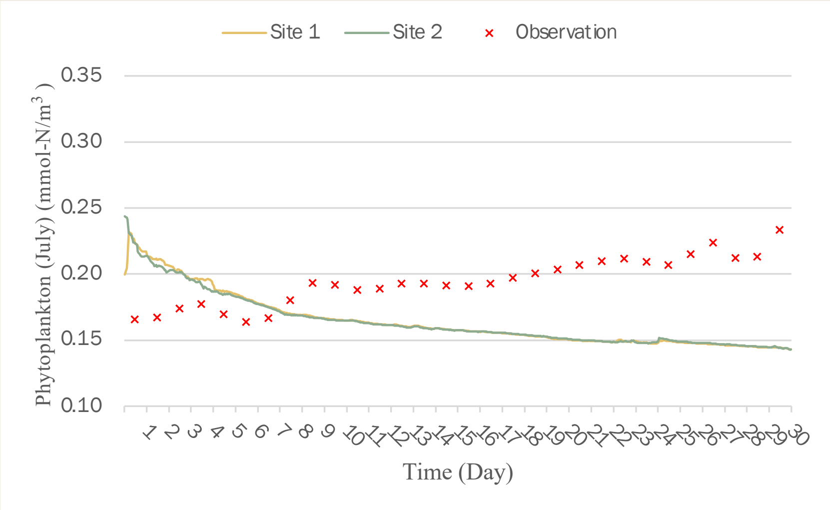
Time series of the nutrient at surface

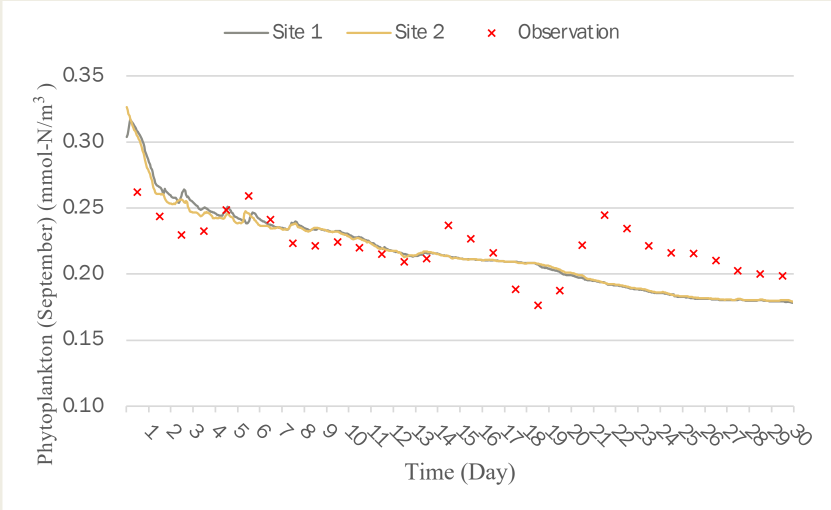




- Simulation of July basically fit in time variation.
  In the last five days of the simulation, there was a sharp increase in the observation part, and here it is suspected that meteorological changes caused the sudden changes in nutrient values.
- September simulation results did not perfectly reproduce the fluctuations of observational nutrient levels over time. However, under the existing conditions, the error was within the tolerable range.

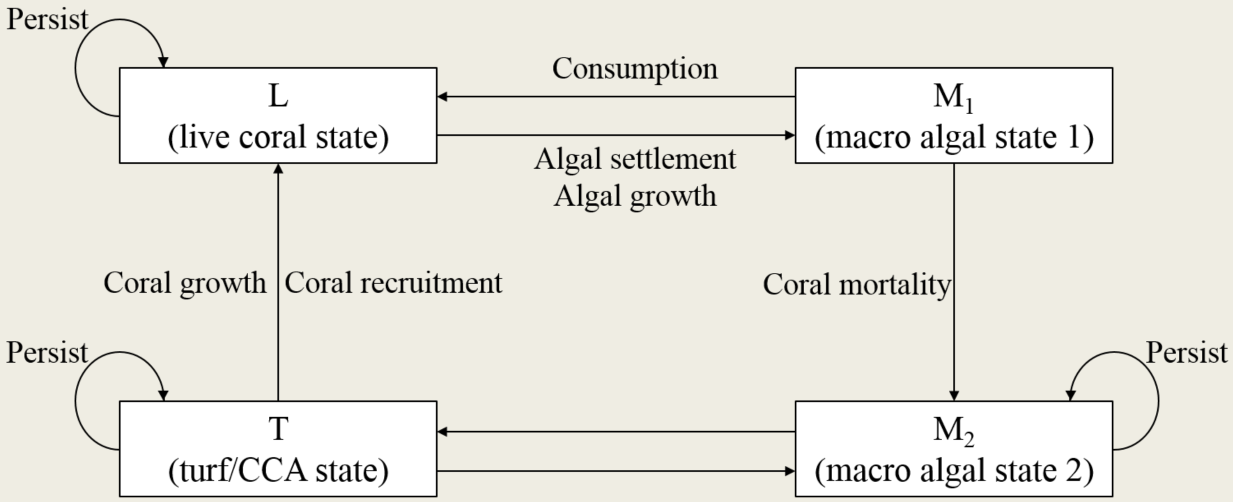
Time series of the phytoplankton at surface





- The probability that the simulation results in July showed the opposite trend to the observation was that the data related to zooplankton didn't match the real situation due to the lack of field data.
- The simulation results in September were more consistent with the observation. Although some peaks were not represented, the general trend and range of values were close to the observation.

Coral-Algae Competition Model



Model structure (refer to Muthukrishnan, R., O. Lloyd-Smith. J. & Fong, P.[7])

Each individual process probabilities can be calculated at every location for each time as:

$$P(consumption) = 1 - e^{-\sigma_h H \Delta t}$$

$$P(algal\ growth) = 1 - e^{-\sigma_a N(1-H) A_a \Delta t}$$

$$P(algal\ settlement) = 1 - e^{-\sigma_p N(1-H) \Delta t}$$

$$P(coral\ recruitment) = 1 - e^{-\sigma_r r \Delta t}$$

$$P(coral\ growth) = 1 - e^{-\sigma_c L_c A_c \Delta t}$$

- The coral-algae competition model is a stochastic cellular automaton model using the R programming language to evaluate the dynamics of coral and algal competition for space under varying environmental conditions.
- Model is structured as a grid of cells where the state of each cell is defined by the main benthic community member occupying it.

Coral-Algae Competition Model

- In this model, feedback processes in local communities could modify these conditions, so local nutrient supply (N) and herbivory pressure (H) for each cell are required and they are calculated from inputted **Nutrient supply** and **Consumer abundance**.

Local nutrient supply

$$N = n(1 + yL_a)$$

Local herbivory pressure

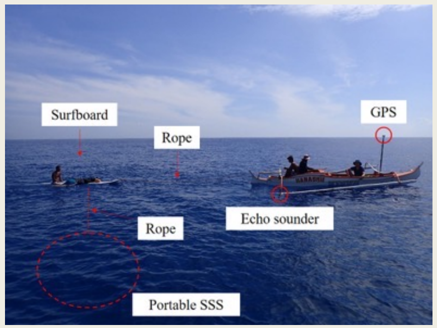
$$H = h(1 - f + fL_c)$$

Symbol	Parameter
n	Nutrient supply
h	Consumer abundance
y	Efficiency of algal nutrient cycling
f	Herbivore spatial fidelity
L_a	Abundance of algae
L_c	Abundance of coral

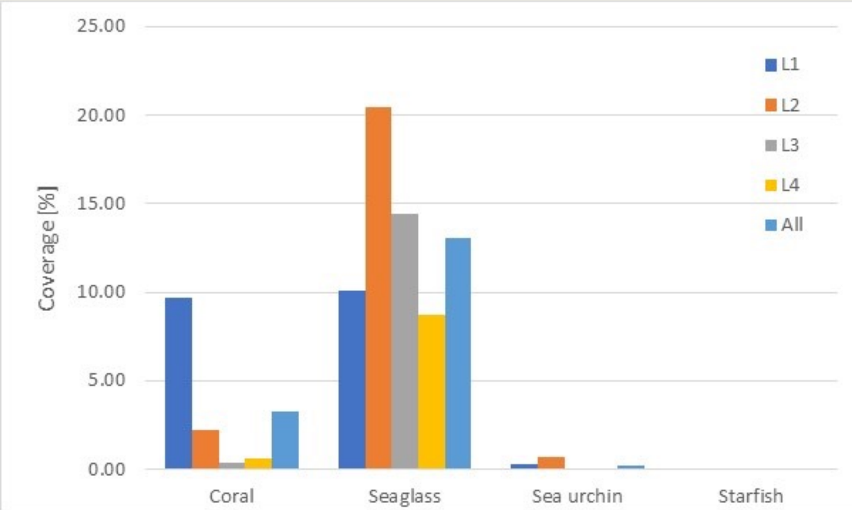
- These parameters are taken as a range in the research.
- One grid of MEC model was set as simulation area for competition model. (200m×200m scale)

Field Survey Result

Obtained from Mizuno's project



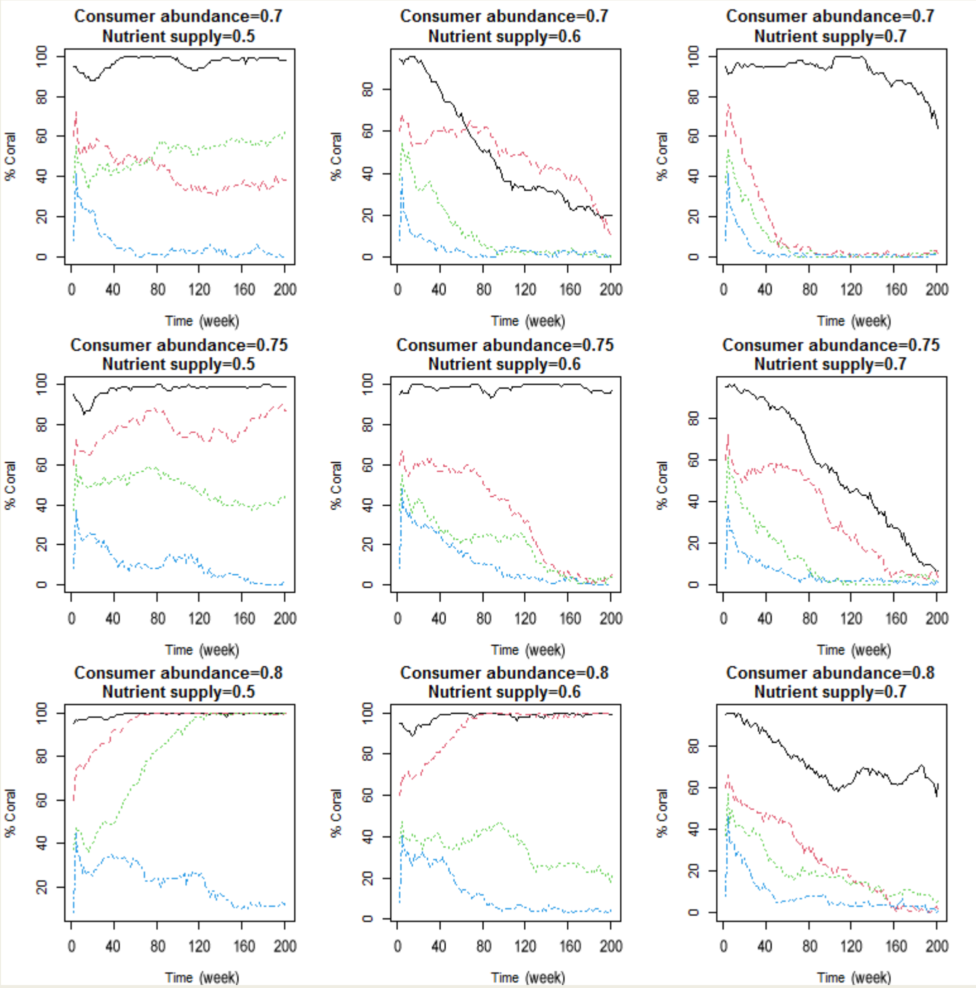
Field Survey Result



Line	Coral	Seagrass	Sea urchin	Starfish	Others
L1	9.66	10.09	0.29	0.02	79.93
L2	2.23	20.45	0.68	0.02	76.62
L3	0.39	14.40	0.00	0.00	85.21
L4	0.62	8.69	0.02	0.00	90.67
All	3.29	13.07	0.24	0.01	83.39

- The result of this field survey was used to set the background for the scenario setting.
- The initial nutrient level and herbivory pressure of Pujada Bay at the current environmental background were measured by comparing the field survey results with the competition model simulation results.

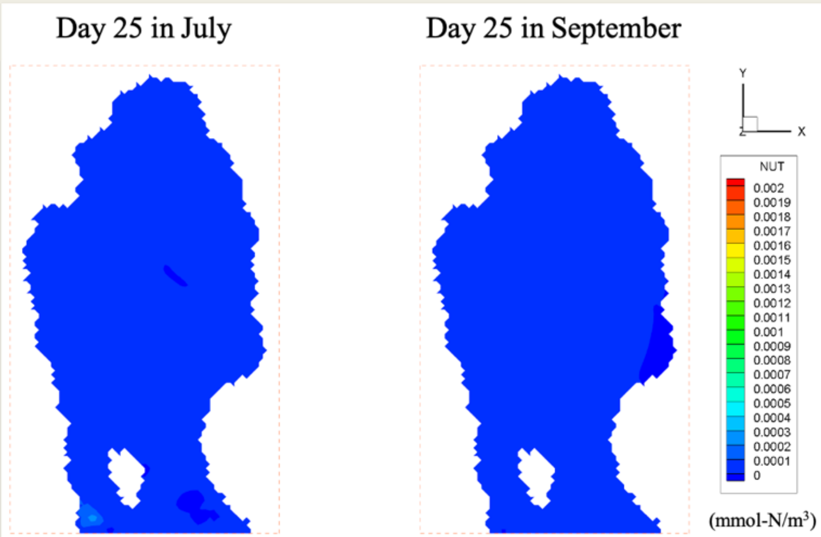
Simulation Result



- The final abundance of corals in the simulation grid was calculated from random initial abundance distributed in a 10%–90% range after 200 weeks. (approximately 3.8 years long)
- At higher nutrient levels, the abundance of corals was decreased, while it was also limited by herbivory pressure.
- By comparison with the field survey, it was concluded that the nutrient supply level in Pujada Bay ranged from 0.6 to 0.7, while the consumer abundance ranged from 0.75 to 0.8.

Scenario Setup

- Generally, one of the key factors that have a large impact on the environment of the bay is the river that flows into the bay.
- However, the flow of the rivers along Pujada Bay is very low and the impact on the bay environment is negligible.
- Other possible ways of inputting nutrient loads need to be considered.



Horizontal distribution of the surface nutrient changes under impact of rivers

River	Magum River (Magum) Matiao Creek (Interco) Pahamutang Creek (Dumping)	
Parameter	July	September
Discharge (m^3/s)	Same as previous	Same as previous
Scene1: Nutrient ($mmol\text{-}N/m^3$)	0.1435 (Initial value)	
Scene2: Nutrient ($mmol\text{-}N/m^3$)	0.4305 (initial value × 3)	

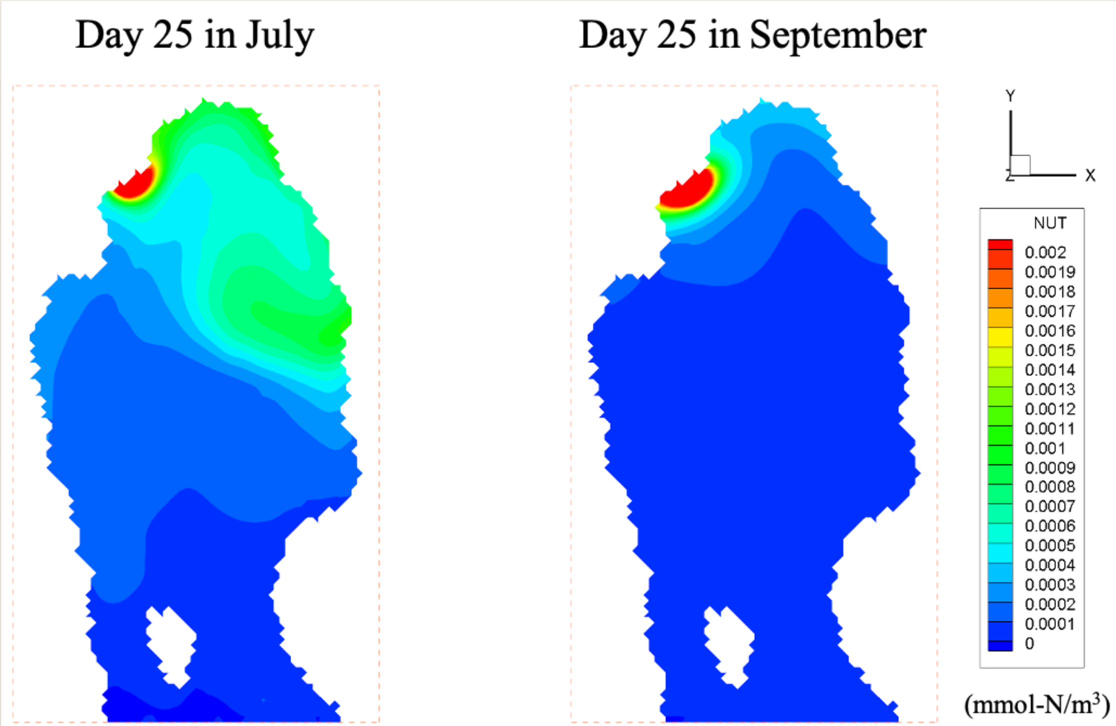
Scenario Setup

(Refer to Google Map)

- The waste from aquaculture, mainly from fish pens/cages, is considered as one of the possible causes of water quality deterioration in Pujada Bay.
- As a reference, data related to aquaculture in Manila Bay[8] were used in this research to roughly estimate the nutrient emission.

Location	Area of fish pens/cages (ha)	Feeds (kg/day)	Annual input of N (MT)
Manila Bay[8]	332.50	51910.00	32,530.62
Pujada Bay	~1.00	~156.12	~97.84

Simulation Result



Horizontal distribution of the surface nutrient changes under impact of aquaculture

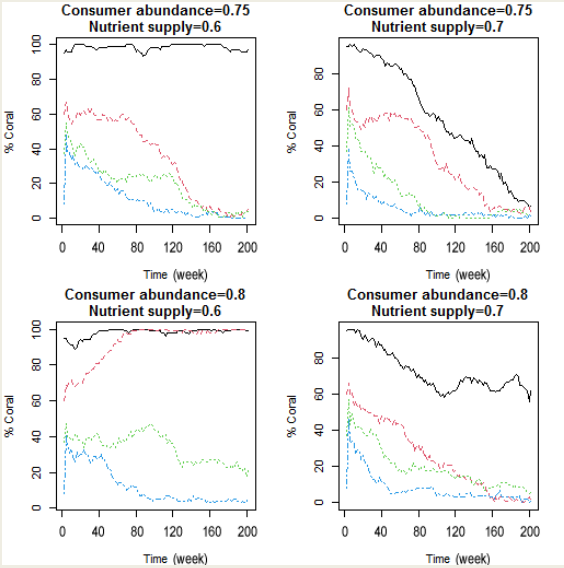
Average nutrient (mmol-N/m^3) for Site 1 and 2 with and without the impact of aquaculture

NO.	Site 1	
Aquaculture	No	Yes
July	0.0022	0.0030
September	0.0048	0.0053
NO.	Site 2	
Aquaculture	No	Yes
July	0.0020	0.0029
September	0.0045	0.0051

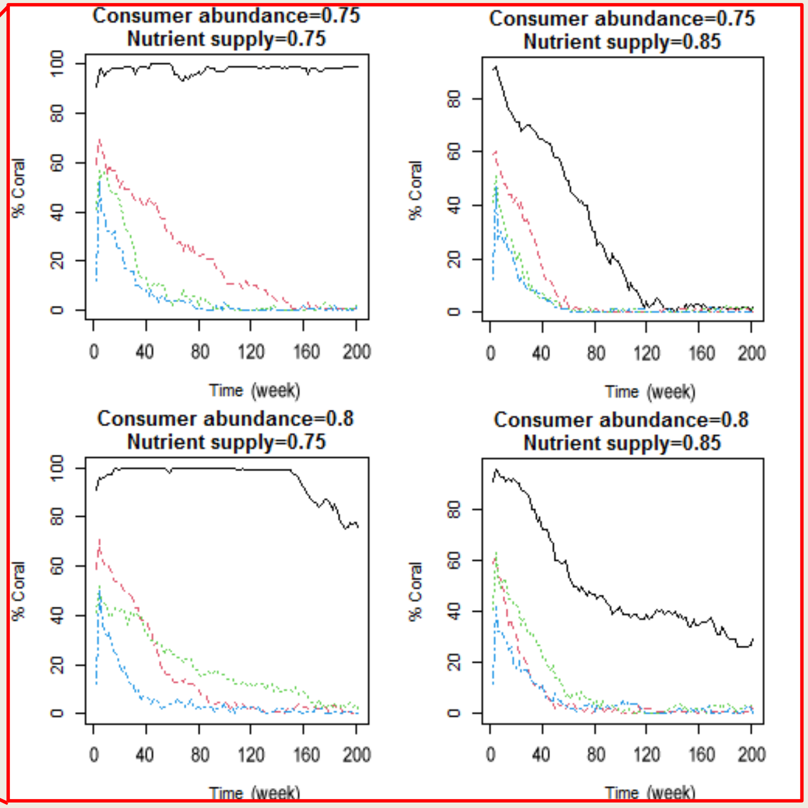
Basically 1.22 times higher

- The impact of aquaculture pens/cages and the transport of nutrients to the whole Pujada Bay can be underpinned. In general terms, nutrient input mainly affected the area in the northern part of the bay.

Simulation Result



(Before)



(After)

- In most cases, coral abundance eventually moved to an extremely low level, which also implied a high probability that coral state would be replaced by other benthic communities under conditions of high nutrient supply.

Conclusions

- The water quality and coral-algae habitat of Pujada Bay region was simulated stably by MEC-NEST model combined with competition model with the available input data.
- The nutrient level in the surface layer of water was elevated under the impact of aquaculture, which indicated that aquaculture might be highly potential as an environmental risk factor for Pujada Bay.
- Due to the lack of observation data, the accuracy of the model could not be confirmed, which requires follow-up research.

Future Work

- Collecting relevant observation data, inputting them into the model and calculating simulations, and then comparing them with the observation data to further minimize the errors is a necessary task in the future.
- A simulation of longer simulation period is also more in line with the current need to show the seasonal changes if the required data are available.
- More details need to be discussed on the linkage between the MEC-NEST model and the competition model.

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7. Muthukrishnan, R., O. Lloyd-Smith. J. & Fong, P. (2016) Mechanisms of resilience: empirically quantified positive feedbacks produce alternate stable states dynamics in a model of a tropical reef.
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Reference

Hydrodynamics and Water Quality Model

MEC-NEST Model (Hydrodynamics Model)

- The MEC Ocean Model was first proposed and developed by the Marine Environmental Committee of the Society of Naval Architects and Ocean Engineers of Japan[2], to numerically study the three-dimensional coastal hydrodynamics.
- Here MEC-NEST model was adopted to calculate the three-dimension tidal elevation, current flows, as well as water temperature and salinity.

Hydrodynamics and Water Quality Model

NPZF Pelagic Ecosystem Model (Water Quality Model)

- NPZF pelagic ecosystem model was introduced to calculate Nutrient concentration (N), Phytoplankton density (P), Zooplankton density (Z), and Fish density (F).