MTEC-ICMASS 2024

Environmental assessment of ammonia bunkering

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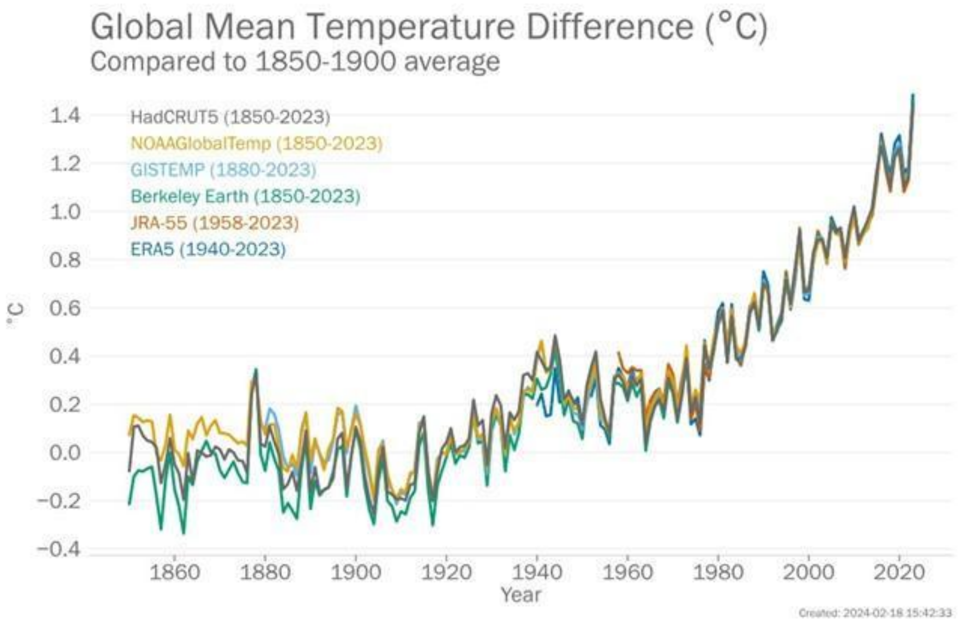
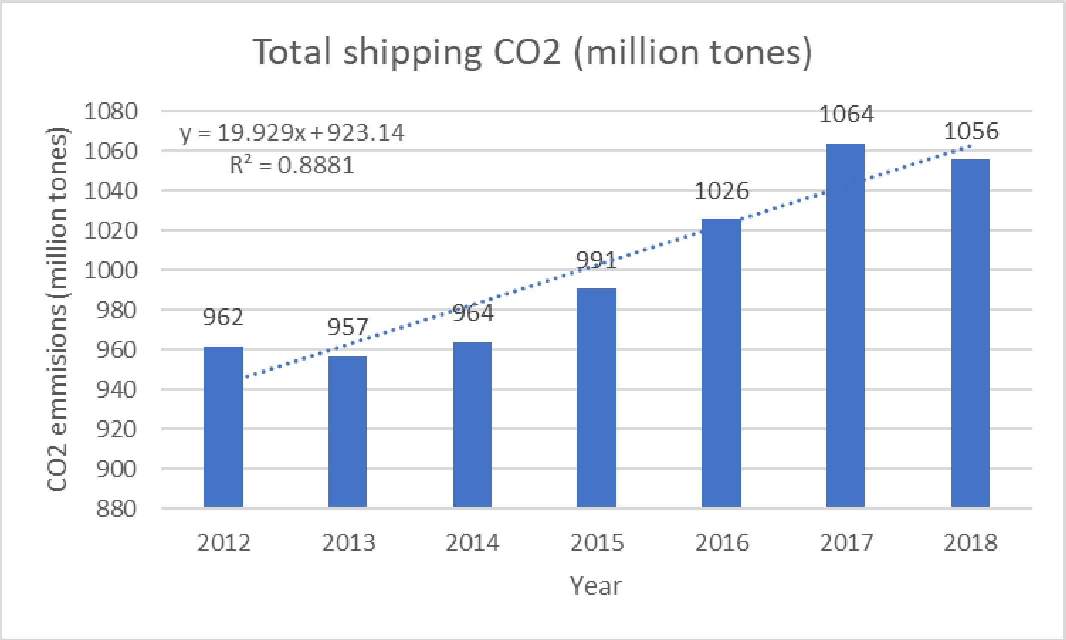
29 October 2024



Annual global mean temperature anomalies (relative to 1850–1900) from 1850 to 2023. Data are from six data sets (State of the Global Climate 2023, WMO)



Global CO2 emission of total shipping from 2012 to 2018 (Fourth Greenhouse Gas Study 2020, IMO)

Target:

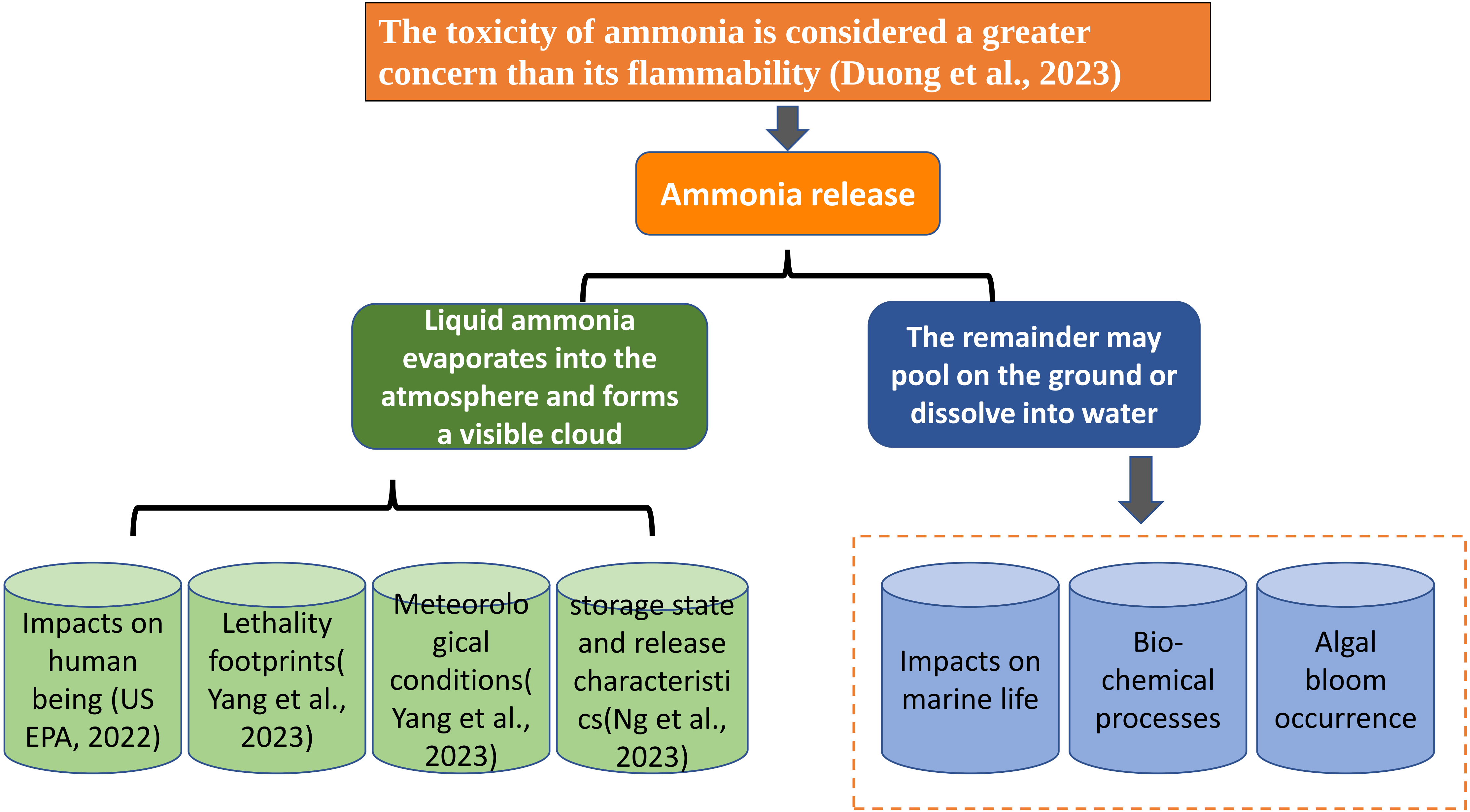
Reduce total annual shipping GHG emissions by at least 50% by 2050 compared to 2008 levels (IMO, 2023)

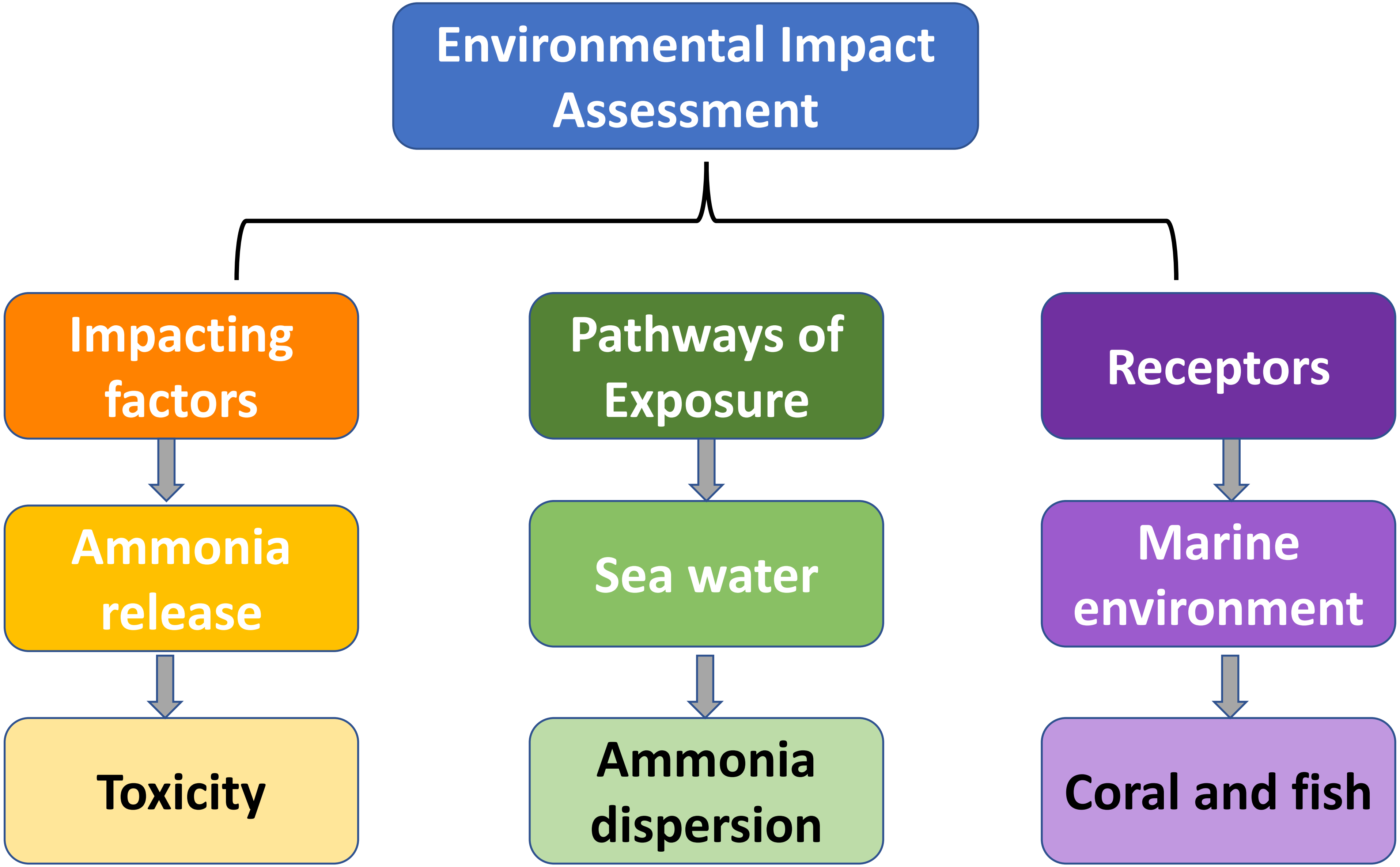
Alternative fuels:

- **Ammonia**
- **Methanol**
- **Ethanol**
- **Hydrogen**
- **Etc.**

Assessments:

- **Engine and fuel system**
- **Emission reduction**
- **Safety**
- **Environmental impacts**
- **Costs**
- **Etc.**


The toxicity of ammonia is considered a greater concern than its flammability (Duong et al., 2023)
Ammonia release
Liquid ammonia evaporates into the atmosphere and forms a visible cloud
The remainder may pool on the ground or dissolve into water
Impacts on human being (US EPA, 2022)
Lethality footprints(Yang et al., 2023)
Meteorolo gical conditions(Yang et al., 2023)
storage state and release characteristi cs(Ng et al., 2023)
Impacts on marine life
Bio-chemical processes
Algal bloom occurrence

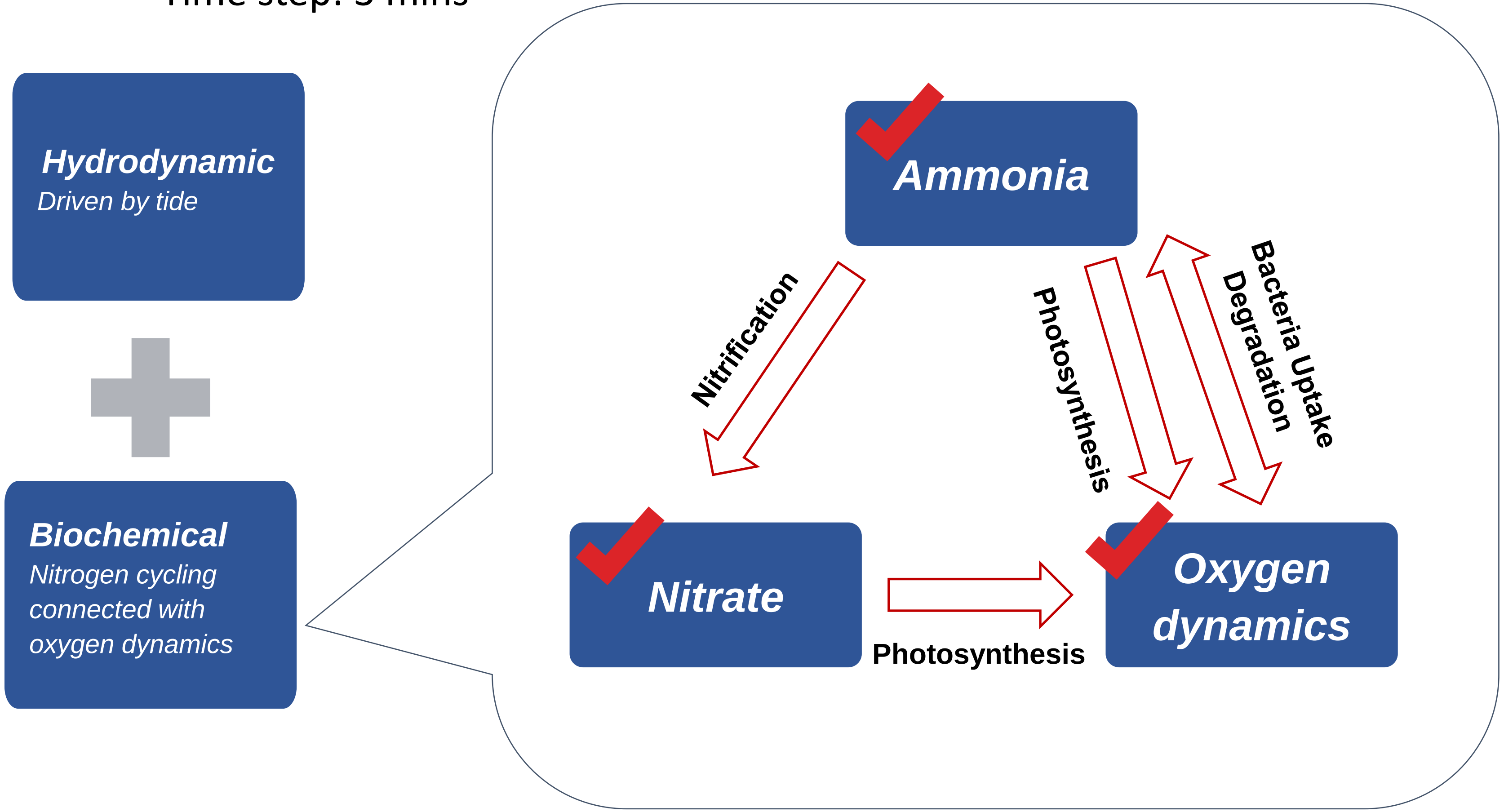

Environmental Impact Assessment
Impacting factors
Pathways of Exposure
Receptors
Ammonia release
Sea water
Marine environment
Toxicity
Ammonia dispersion
Coral and fish

Outlines

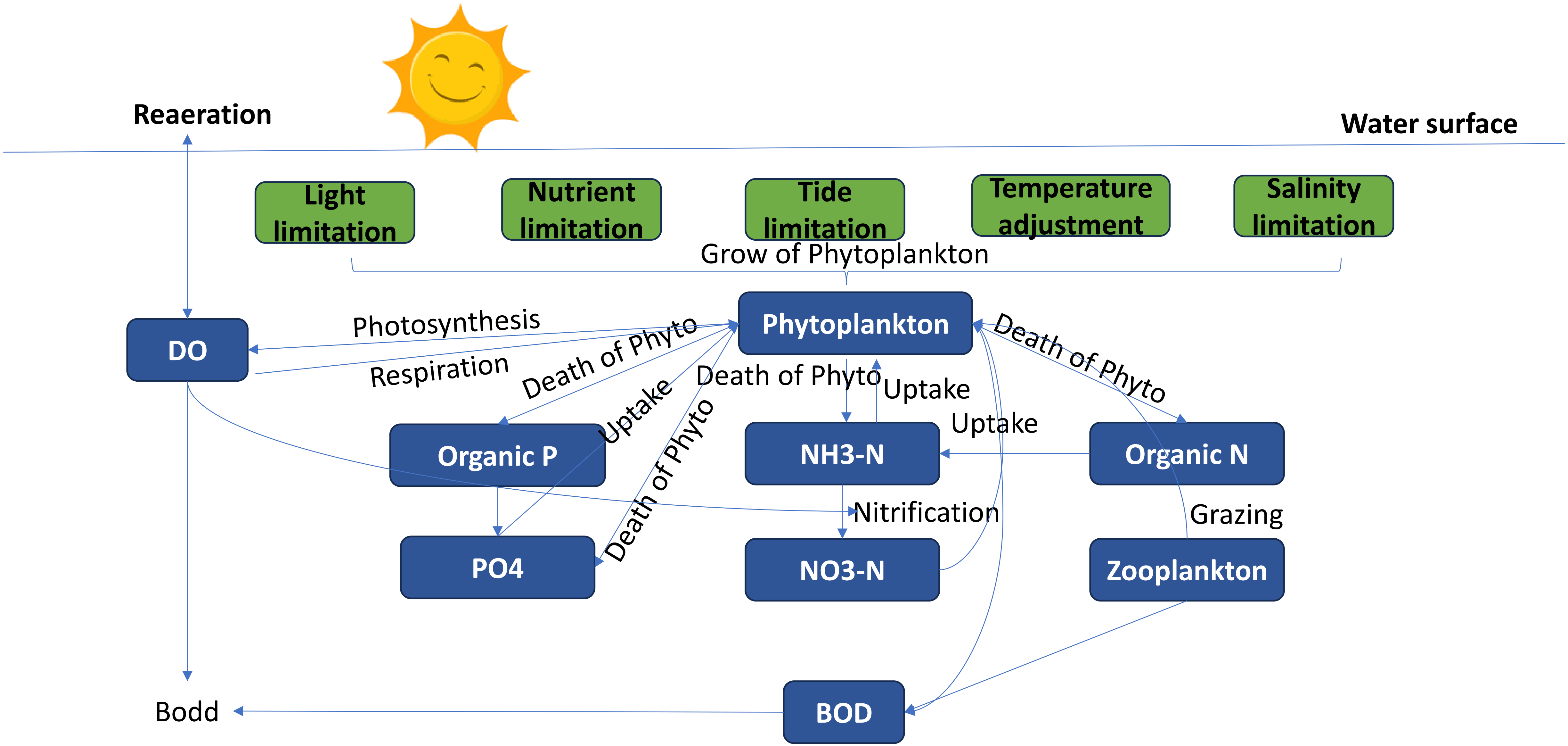
- Model, data and criteria
- **Potential impacts of toxicity of ammonia on coral and fish**
- Results

A numerical model (EUTRO) combining hydrodynamic module and biochemical module has been established

- **Resolution**
  - Space: ~60 m at Banyan, 300-400 m at Raffles Reserved Anchorage
  - Time step: 3 mins

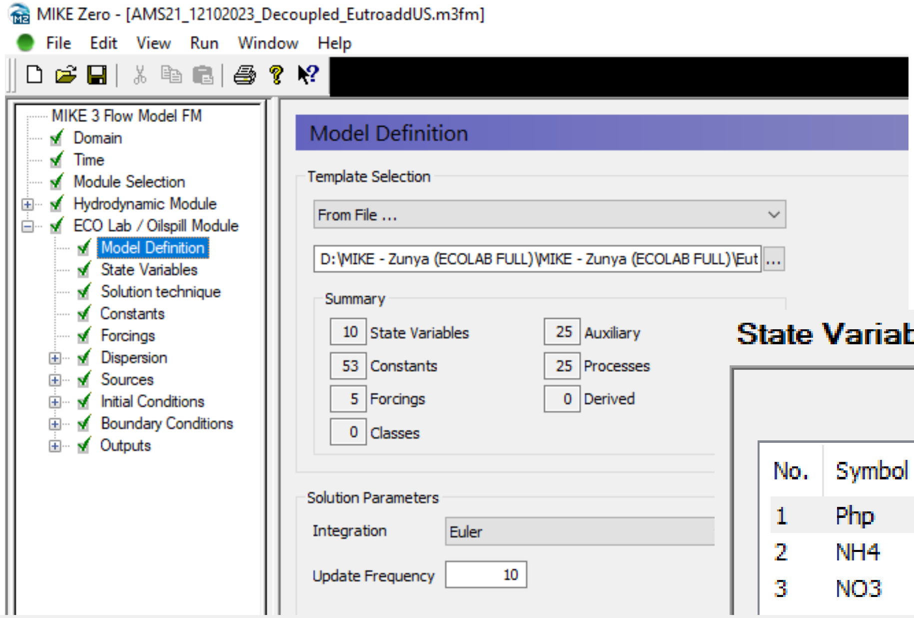


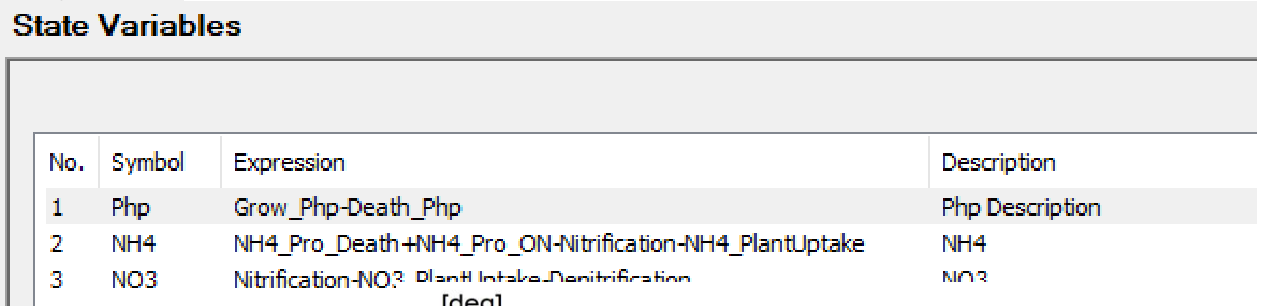
Kinetics of the eutrophication module

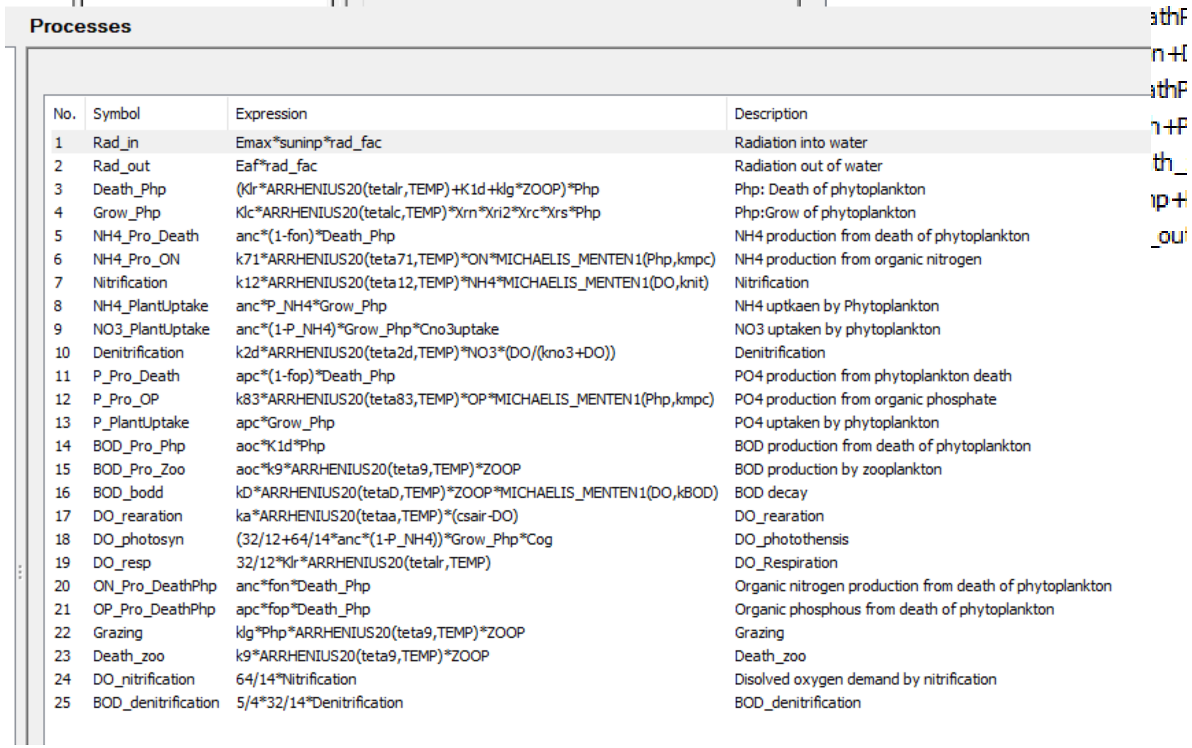


EUTRO model in MIKE

There are 9 state variables, 53 parameters, 25 processes included in the biochemical module.

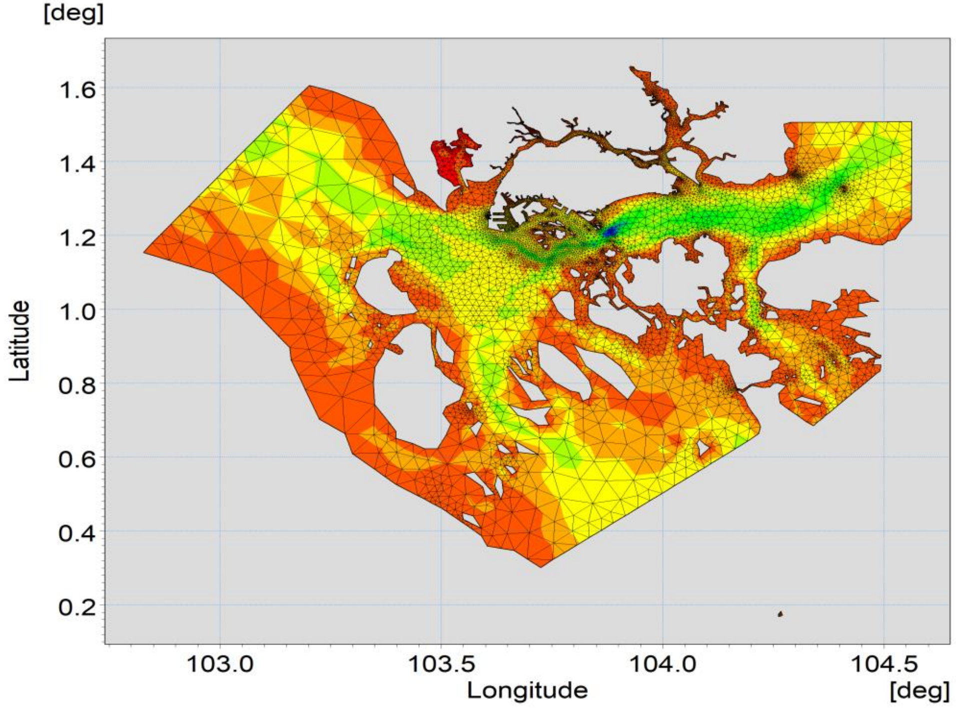






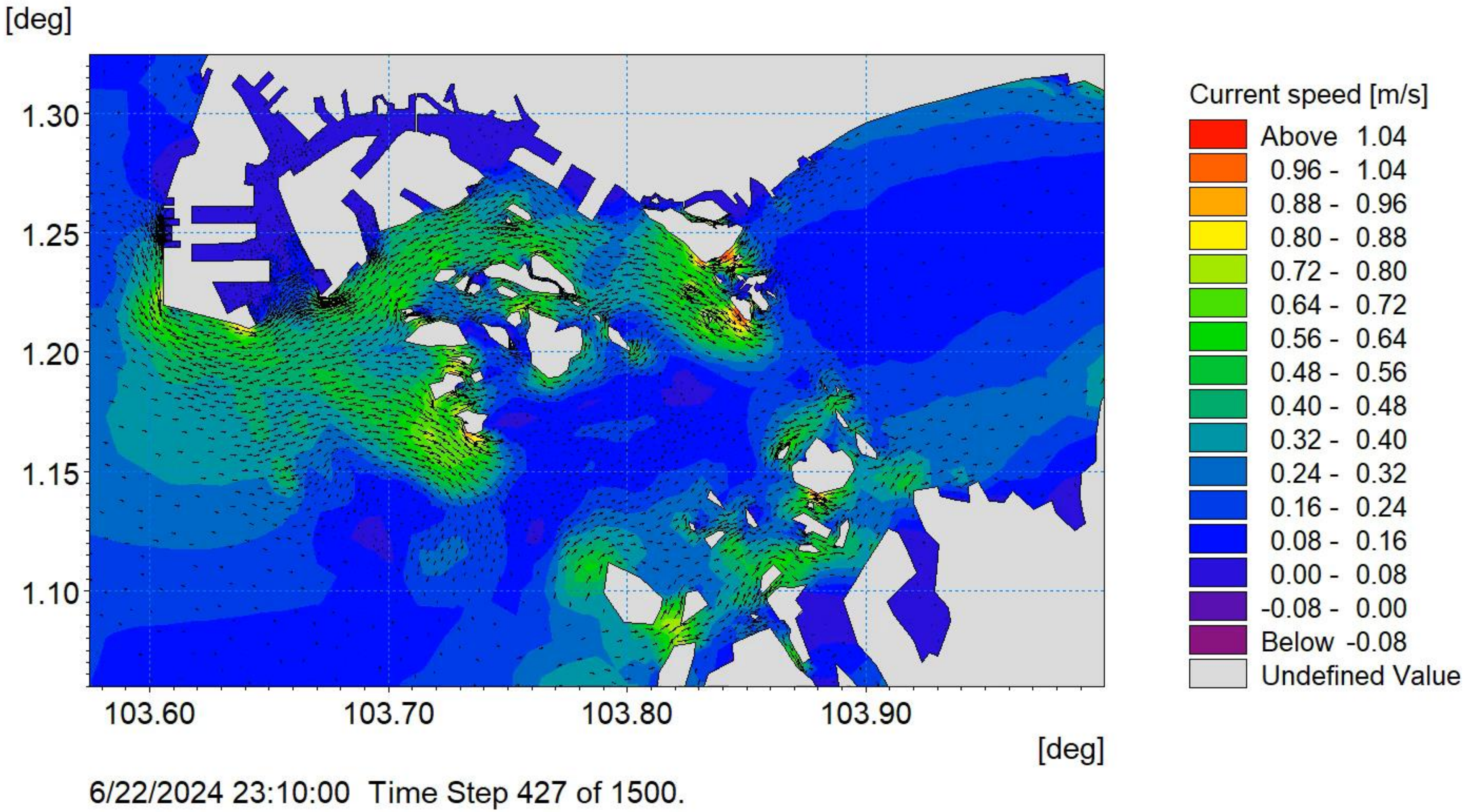
Processes

No.	Symbol	Expression	Description
1	Rad_in	Emax*suninp*rad_fac	Radiation into water
2	Rad_out	Eaf*rad_fac	Radiation out of water
3	Death_Php	(Klr*ARRHENIUS20(tetalr,TEMP)+K1d+klg*ZOOP)*Php	Php: Death of phytoplankton
4	Grow_Php	Klc*ARRHENIUS20(tetalc,TEMP)*Xrn*Xri2*Xrc*Xrs*Php	Php:Grow of phytoplankton
5	NH4_Pro_Death	anc*(1-fon)*Death_Php	NH4 production from death of phytoplankton
6	NH4_Pro_ON	k71*ARRHENIUS20(teta71,TEMP)*ON*MICHAELIS_MENTEN1(Php,kmpc)	NH4 production from organic nitrogen
7	Nitrification	k12*ARRHENIUS20(teta12,TEMP)*NH4*MICHAELIS_MENTEN1(DO,knit)	Nitrification
8	NH4_PlantUptake	anc*P_NH4*Grow_Php	NH4 uptkaen by Phytoplankton
9	NO3_PlantUptake	anc*(1-P_NH4)*Grow_Php*Cno3uptake	NO3 uptaken by phytoplankton
10	Denitrification	k2d*ARRHENIUS20(teta2d,TEMP)*NO3*(DO/(kno3+DO))	Denitrification
11	P_Pro_Death	apc*(1-fop)*Death_Php	PO4 production from phytoplankton death
12	P_Pro_OP	k83*ARRHENIUS20(teta83,TEMP)*OP*MICHAELIS_MENTEN1(Php,kmpc)	PO4 production from organic phosphate
13	P_PlantUptake	apc*Grow_Php	PO4 uptaken by phytoplankton
14	BOD_Pro_Php	aoc*K1d*Php	BOD production from death of phytoplankton
15	BOD_Pro_Zoo	aoc*k9*ARRHENIUS20(teta9,TEMP)*ZOOP	BOD production by zooplankton
16	BOD_bodd	kD*ARRHENIUS20(tetaD,TEMP)*ZOOP*MICHAELIS_MENTEN1(DO,kBOD)	BOD decay
17	DO_rearation	ka*ARRHENIUS20(tetaa,TEMP)*(csair-DO)	DO_rearation
18	DO_photosyn	(32/12+64/14*anc*(1-P_NH4))*Grow_Php*Cog	DO_photothensis
19	DO_resp	32/12*Klr*ARRHENIUS20(tetalr,TEMP)	DO_Respiration
20	ON_Pro_DeathPhp	anc*fon*Death_Php	Organic nitrogen production from death of phytoplankton
21	OP_Pro_DeathPhp	apc*fop*Death_Php	Organic phosphous from death of phytoplankton
22	Grazing	klg*Php*ARRHENIUS20(teta9,TEMP)*ZOOP	Grazing
23	Death_zoo	k9*ARRHENIUS20(teta9,TEMP)*ZOOP	Death_zoo
24	DO_nitrification	64/14*Nitrification	Disolved oxygen demand by nitrification
25	BOD_denitrification	5/4*32/14*Denitrification	BOD_denitrification

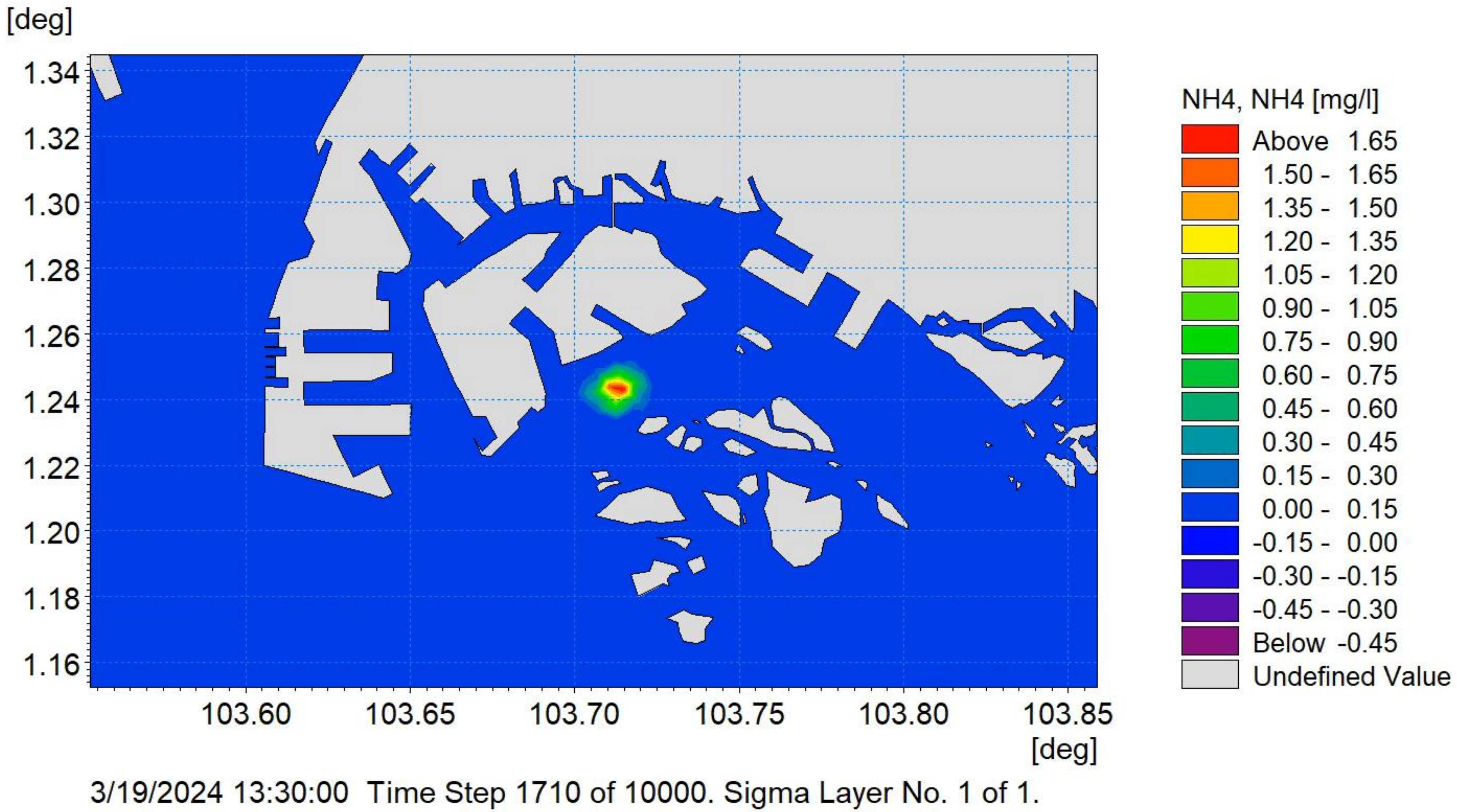


Mesh

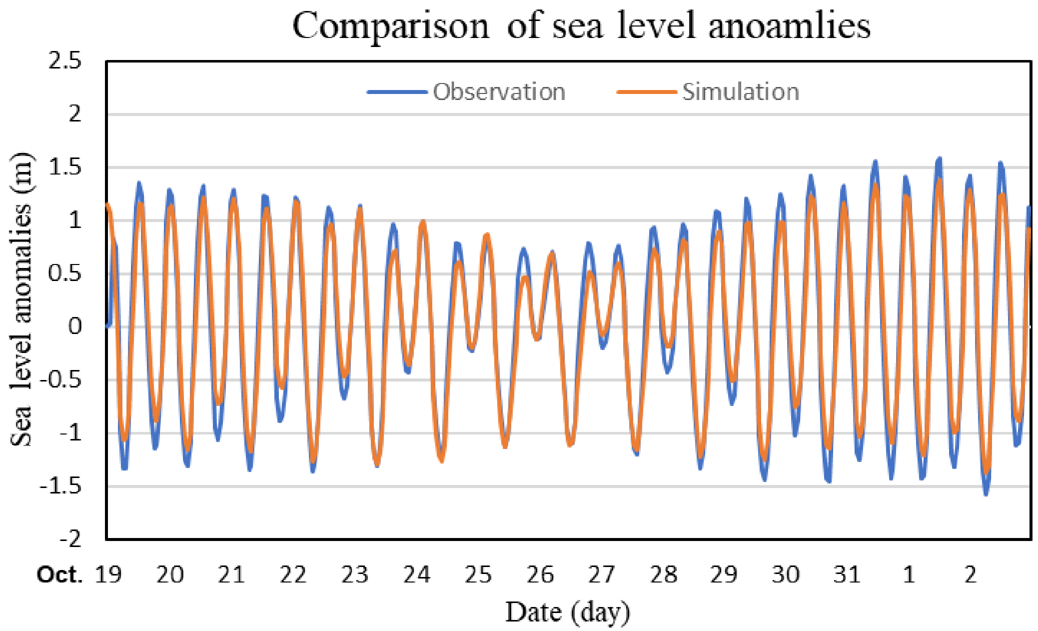
Simulation of current



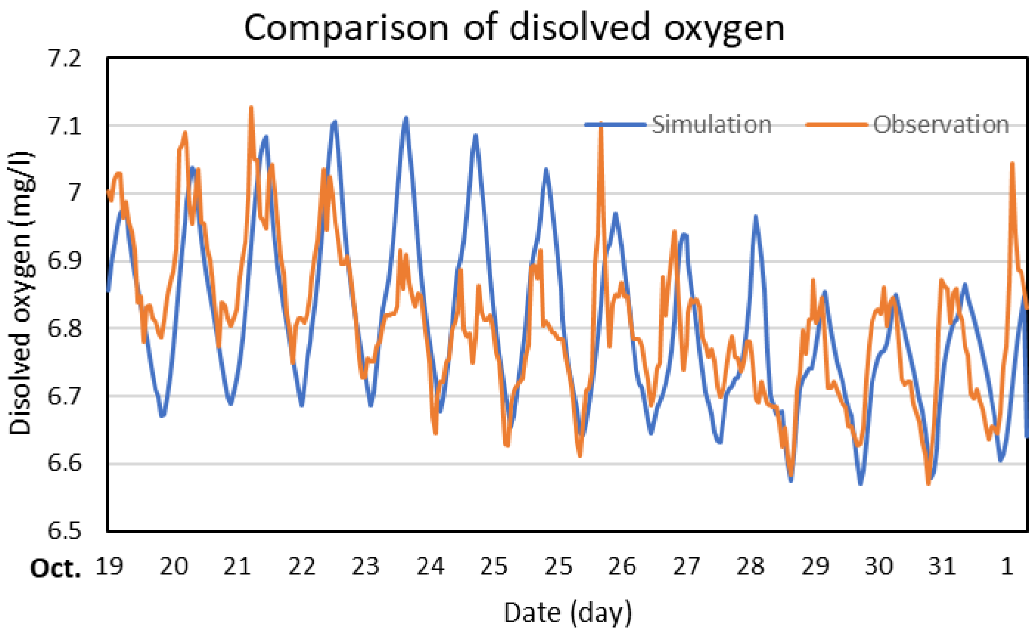
Simulation of ammonia dispersion



Validation of EUTRO model



Simulation of sea surface level compared with observation of tide gauge (Tanjong Pagar)

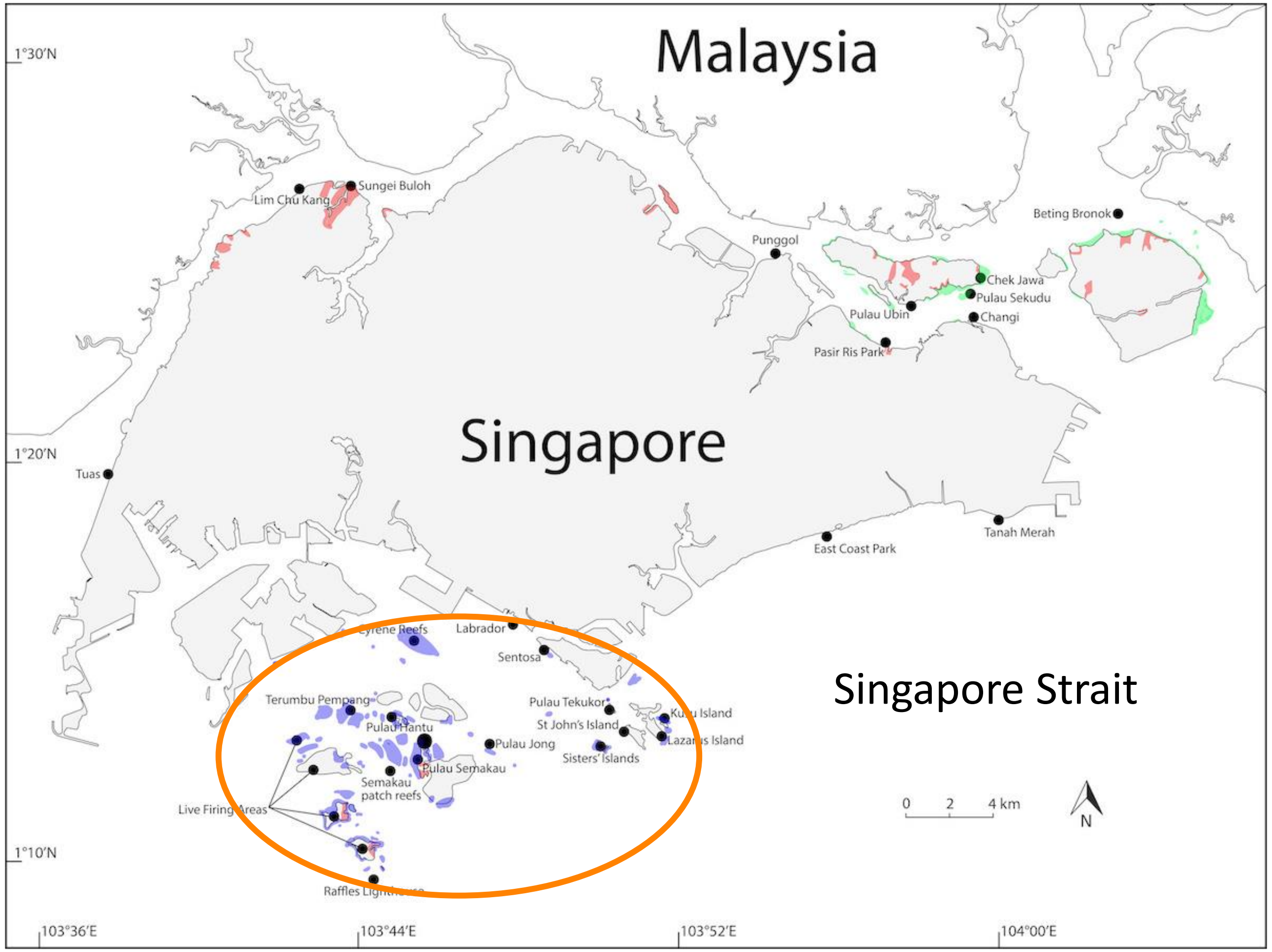


Simulation of dissolved oxygen (DO) compared with observation by Martine et al. (2021)

Observation data: Dissolved oxygen gauge observation dataset with a high resolution of 10 minutes at the Kusu Island of Singapore (103.86°E, 1.226°N) (https://doi.org/10.21979/N9/2FQEGW).

Correlation coefficients exceeding 0.6 and RMSE lower than 0.3 indicate a very good performance of EUTRO.

Coral reef distribution in Singapore



https://coralreef.nus.edu.sg/singapore.html

Receptors:

- **Coral**
- **Fish**

Water quality Criteria

Ammonia

NEA	ASEAN
None	0.07 mg N/L (criteria)

Our adopted definition: Ammonia

Definition	Concentration (mg-N/L)	Rationale
Ambient	**0.007**	Observation (Martin et al. 2022)
LC50 for coral	**0.057**	Toxic to coral (Bussapakorn et al. 2019)
LC50 for fish	**0.21**	Toxic to fish (Okelsrud and Pearson, 2007)

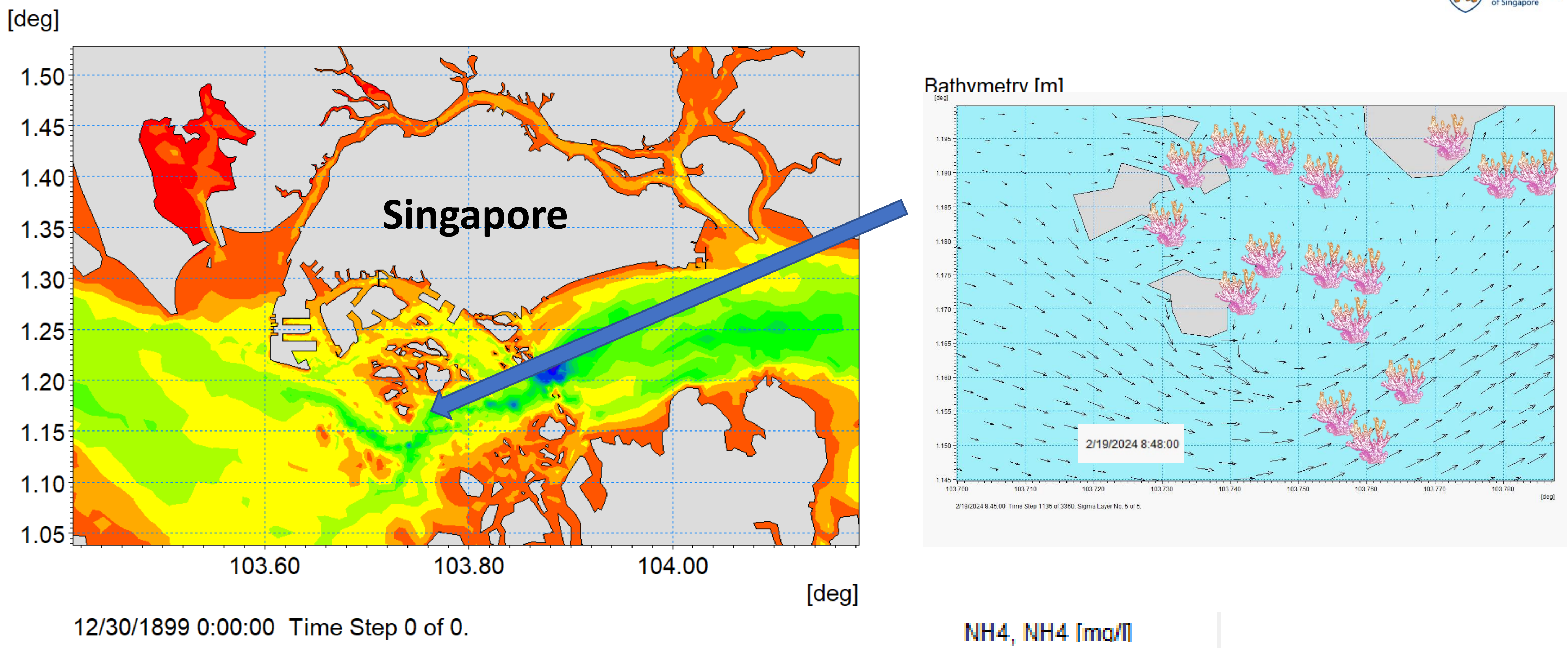
Nitrate

NEA	ASEAN
20 mg-N/L (criteria)	0.06 mg N/L (criteria)

Our adopted definition: Nitrate

Definition	Concentration (mg-N/L)	Rationale
Ambient	**0.028**	Observation (Martin et al. 2022)
ASEAN	**0.06**	ASEAN criteria
NEA	**20**	NEA criteria

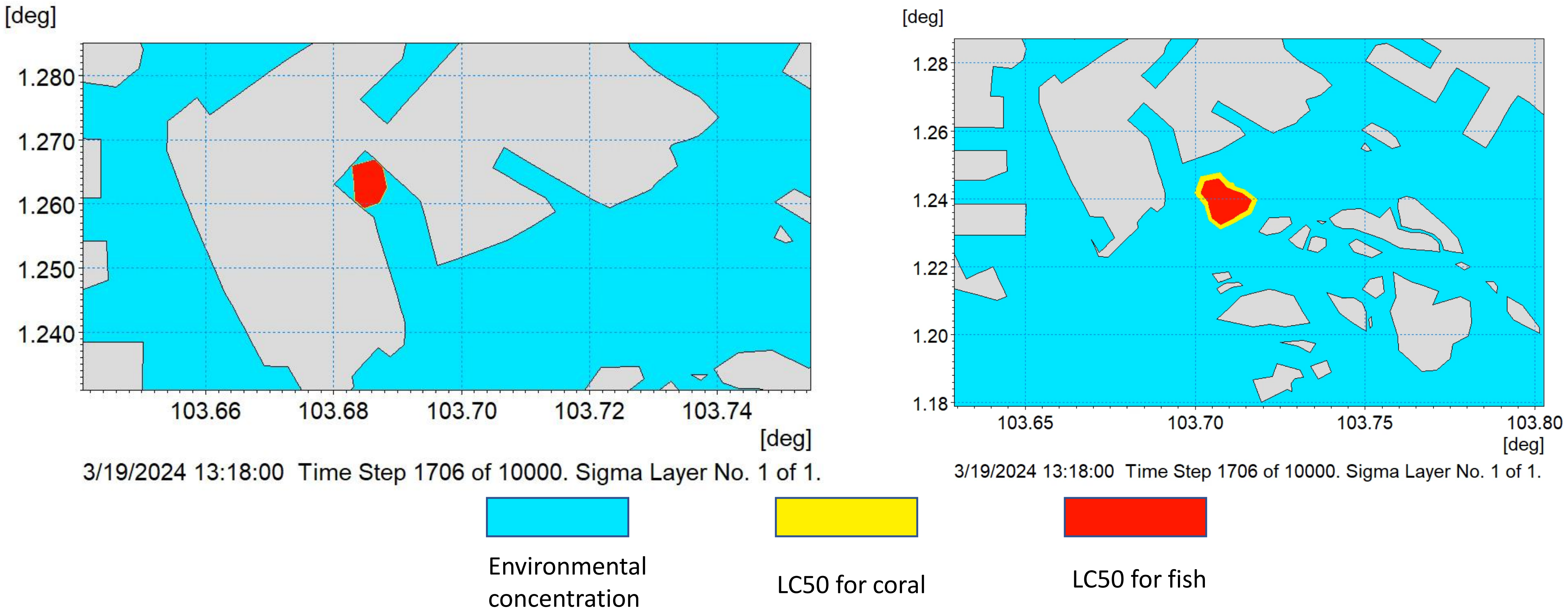
Demonstration of ammonia lethal concentration for coral and fish



NH4, NH4 [mg/l]

- LC 50 fish
- LC 50 coral
- Ambient
- Below 0.007
- Undefined Value

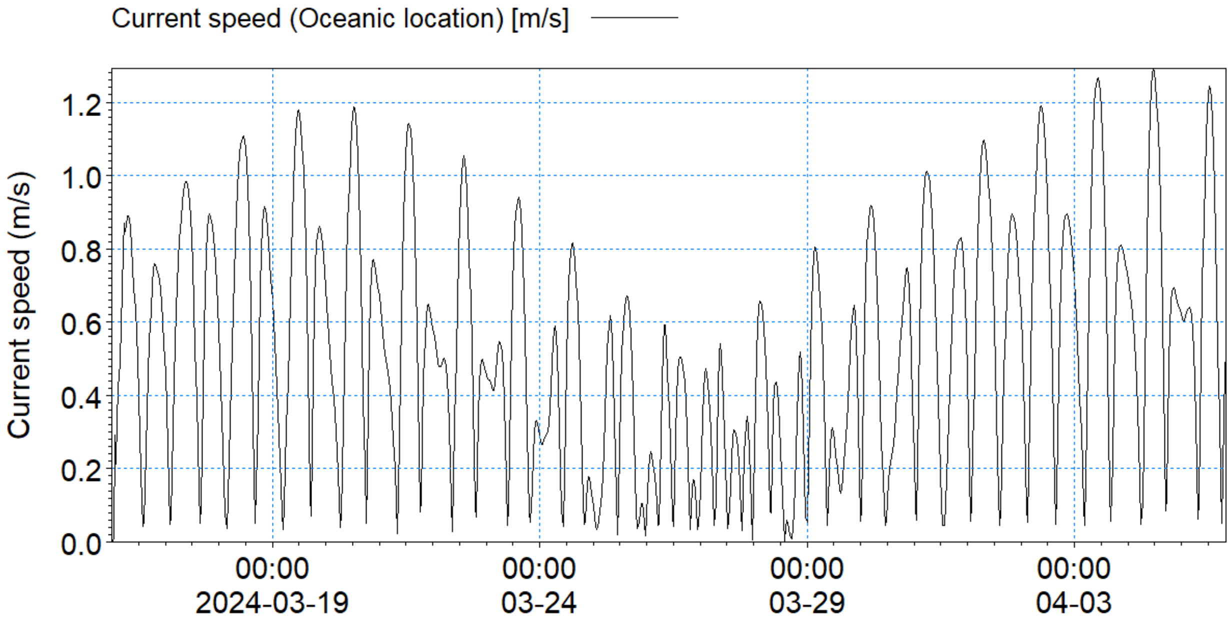
Scenario 1: Different release locations

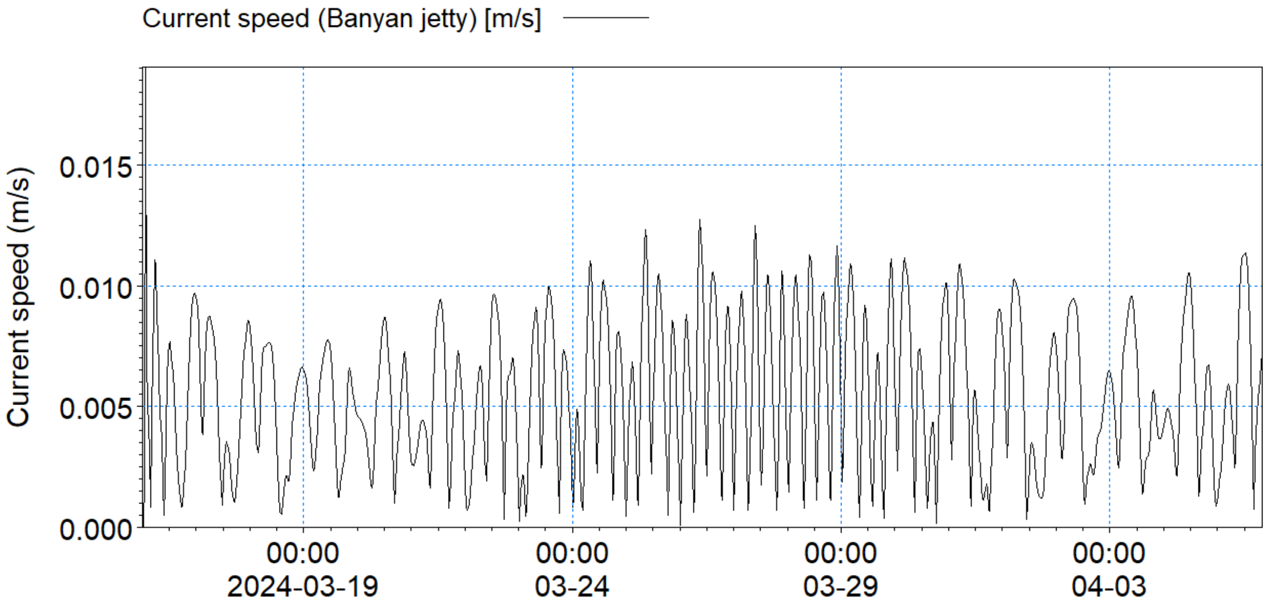


- **The areas affected by LC50 for coral in the jetty is twice as large as that in the oceanic area.**
- **The areas affected by LC50 for fish remain small in both the jetty and the oceanic area.**
- **The LC50 for coral persists for 3 days in the jetty, but only for 7 hours in the oceanic area.**
- **The duration of adverse impacts in the jetty is significantly longer compared to the oceanic area.**

Flowrate: 500 m^3/h
Release duration: 180 seconds
Release time: 13:18 on 19 March 2024 (Low tide)

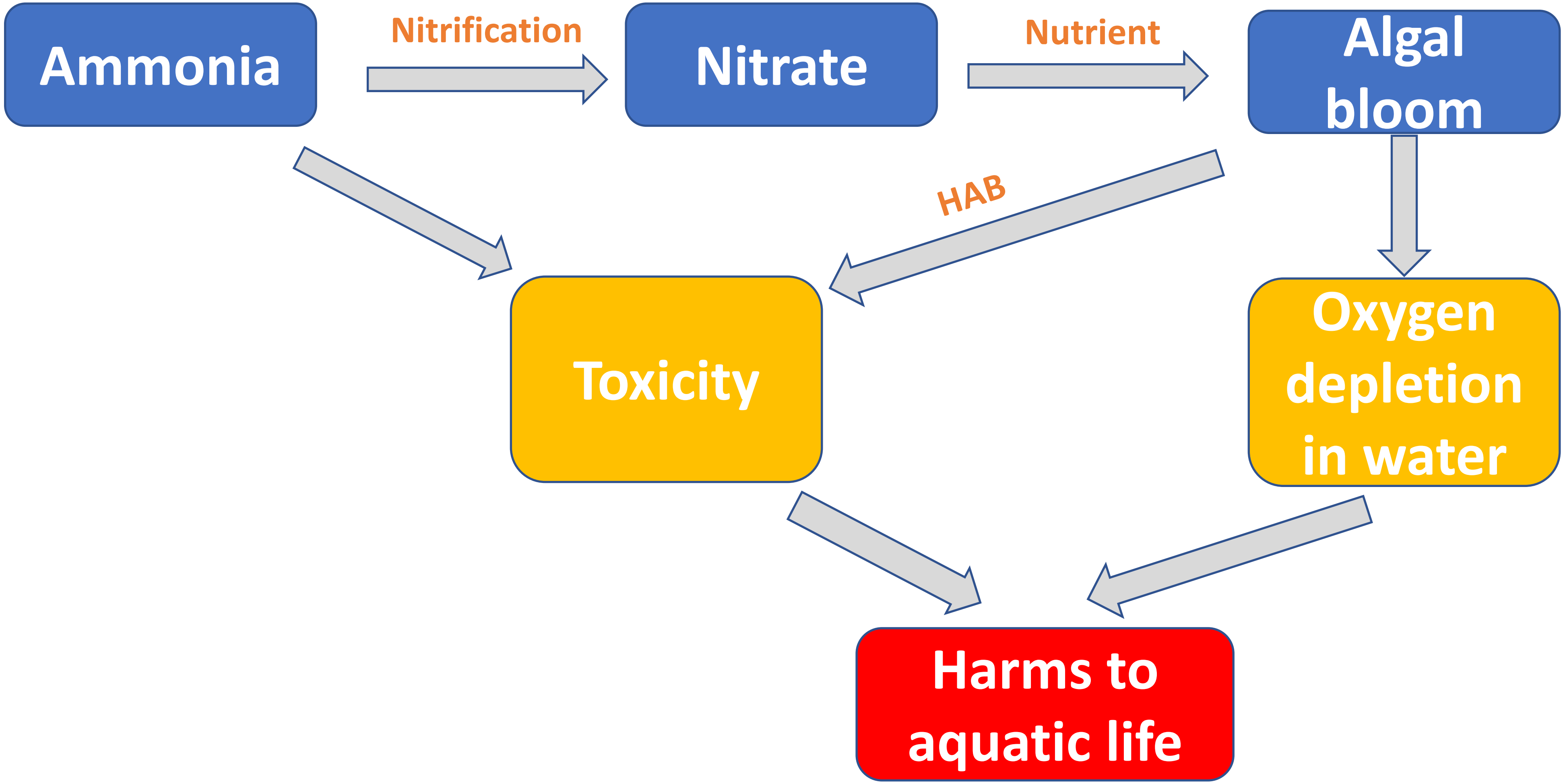
Scenario 1: Different release locations



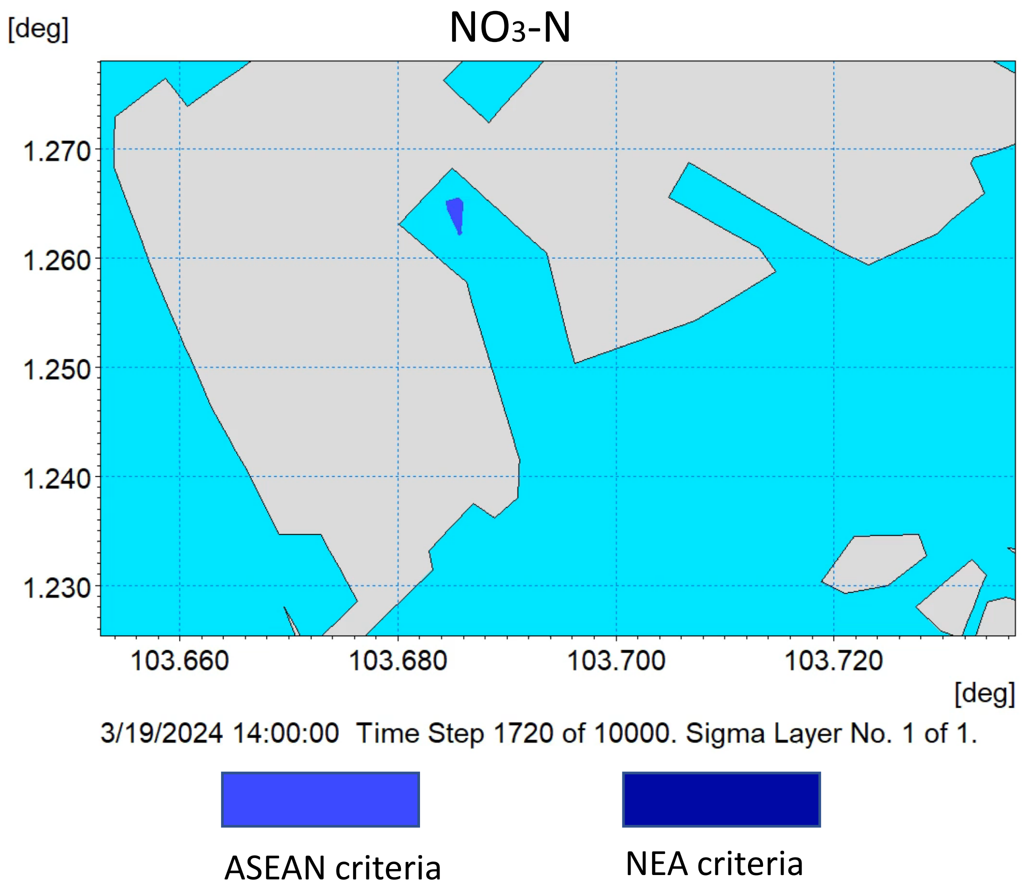


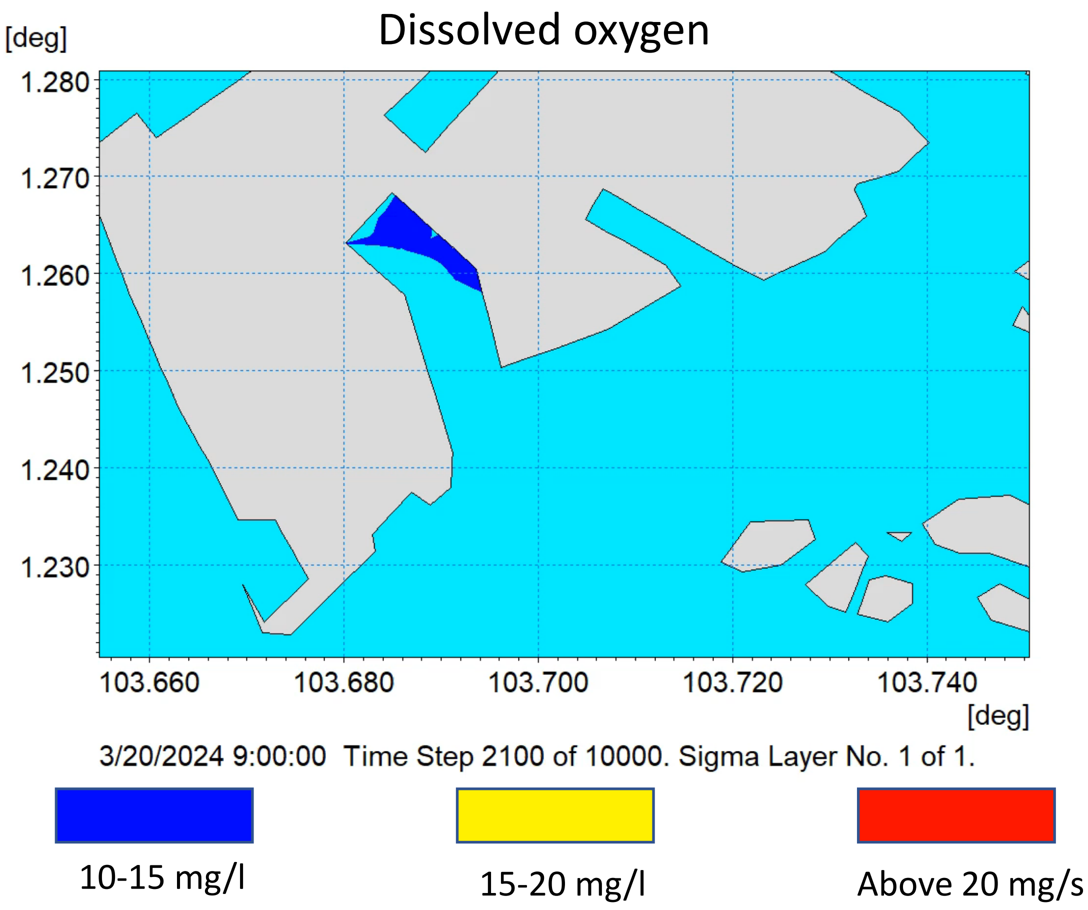
- **Jetty:**
  - **Still water**
  - **Limited affected areas but prolonged duration of lethal concentration**
- **Oceanic area:**
  - **Running water**
  - **Extensive affected areas but short duration of lethal concentration**

Second-derived environmental impacts



Second-derived environmental impacts



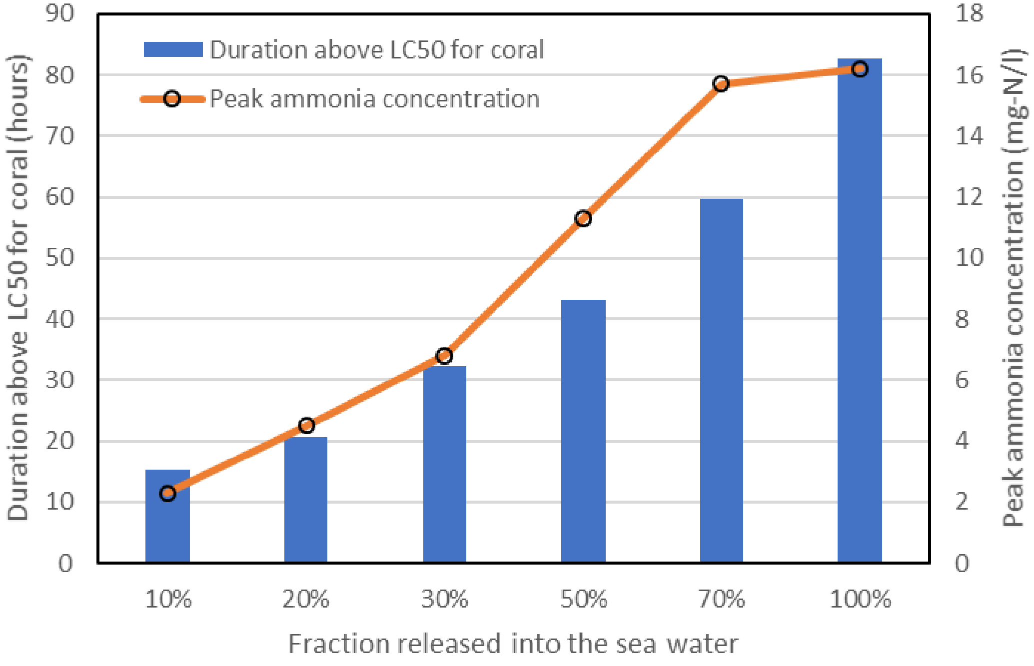


Flowrate: 500 m^3/h
Release duration: 180 seconds
Release time: 13:18 on 19 March 2024 (Low tide)

- **Nitrate nitrogen and dissolved oxygen concentrations increase obviously in the jetty but are not clearly observed in the oceanic areas.**

Scenario 2: Different release quantities

Banyan jetty:
Different percentage of ammonia is released.



% dissolved in seawater	*Duration of exposure to > LC50 $_{coral}$ (hrs)*	*Peak ammonia concentration (mg-N/L)*
10%	15.2	2.3
20%	20.7	4.5
30%	32.2	6.8
50%	43.2	11.3
70%	59.7	15.7
100%	82.7	16.2

- As the percentage of ammonia dissolution decreases, both the exposure time to ammonia LC 50_{coral} concentration and peak ammonia concentration decreases.

Conclusions

- Ammonia dispersion near the jetty is relatively slow due to low current speeds and the obstruction by the jetty. Ammonia lethal concentration for coral can last from one to several days, depending on the release amount.
- In the oceanic areas, ammonia disperses more rapidly due to stronger currents, where the lethal concentration for coral lasts only a few hours.
- As the amount of ammonia released into the sea decreases, the toxic effects of ammonia gradually diminish.
- A continuous increase in ammonia release over time could lead to a rise in the risk of algal blooms, particularly near the jetties.

References

Model settings

- Tkalich P, Sundarambal P. 2003. Eutrophication modelling for the Singapore waters. Singapore Maritime and Port Journal, 122: 136.

Singapore baseline

- Martin, P., Moynihan, M. A., Chen, S., Woo, O. Y., Zhou, Y., Nichols, R. S., ... & Chen, M. (2022). Monsoon-driven biogeochemical dynamics in an equatorial shelf sea: Time-series observations in the Singapore Strait. Estuarine, Coastal and Shelf Science, 270, 107855.

NEA guideline

- Allowable Limits for Trade Effluent Discharge to Controlled Watercourse https://www.nea.gov.sg/our-services/pollution-control/water-quality/allowable-limits-for-trade-effluent-discharge-to-watercourse-or-controlled-watercourse

Ammonia Toxicity to corals

- Bussapakorn, U., Petchporn, C., & Sompop, R. (2019). An effect-analysis method for species-dependent coral health status in temperature and ammonia: A case study of Acropora sp., Turbinaria sp., and Porites sp. E3S Web of Conferences, 93. https://doi.org/10.1051/e3sconf/20199301002
- NCCOS (2020). Effects of Ammonia on Corals and Sea Urchins.

Ammonia Toxicity to fish

- Okelsrud A, Pearson RG. 2007. Acute and postexposure effects of ammonia toxicity on juvenile barramundi (Lates calcarifer [Bloch]). Archives of Environmental Contamination and Toxicology, 53(4): 624–631. https://doi.org/10.1007/s00244-006-0215-z

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Thanks for your attention!

Any comments are welcome!