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GUEST EDITORIAL

Indonesian green tides: the problem is also the solution

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INTRODUCTION

Green tides are unattached blooms of green macroalgae (seaweeds) that occur globally and can attain vast proportions. The main components of the blooms are species of the sea lettuce genus *Ulva*, a sheet-like green seaweed, which can form unusual morphs under these conditions (Blomster et al., 2002). In estuaries and shallow coastal embayments drifting or cast-up macroalgae can reach quantities of up to 27 kg wet weight m^{-2}. Green tides have been researched extensively since Fletcher's (1996) review highlighted their importance, but they came to wide public attention at the time of the 2008 Qingdao Summer Olympics when the Yellow Sea blooms endangered the sailing events. In May–July 2008, prior to the Olympics, the Yellow Sea coastline experienced the world's largest green tide with 1 million tonnes of drifting biomass covering 13,000–30,000 km^2 (Leliaert et al., 2008). Enormous quantities were washed into shallow water and onto the beaches. News reports from the time show volunteers working to remove the biomass and save the events. Green tides have increased in frequency and extent globally over the last few decades, with the most significant blooms continuing to be those in the Yellow Sea (Ye et al., 2011; Ren et al., 2024).

GREEN TIDES: THE PROBLEM

The Ulvophyceae, the most abundant and widespread macroalgae of the blooms, exhibit rapid nutrient uptake and growth rates, nutrient exploitation and storage strategies that clearly contribute to their propensity to produce blooms in nutrient rich shallow waters (Fletcher, 1996). Green tides can persist for up to a dozen years, and can pervasively and fundamentally alter ecosystems.

Green tide blooms undergo sudden explosions followed by catastrophic collapses in late spring or early summer. Degradation of the algal biomass causes complete anoxia and the accumulation of toxic hydrogen sulfide, which results in mass mortality of fauna (including terrestrial animals walking on the shore) and displacement of natural communities of plants and algae. Assemblages of sediment-dwelling fauna are damaged, reducing their biodiversity and their functionality as nutrient recyclers, mixers of sediment and their provision of an important source of food for fish and aquatic birds. Green tides can directly disrupt the feeding of wading birds, which are typically highly protected by environmental legislation (Raffaelli et al., 1998).

In addition to their environmental impacts, macroalgal blooms and their collapse and dystrophic crises also affect human uses of the coastal marine environment. Impacts include interference with fishing and aquaculture activities, and fish and shellfish mortalities due to hypoxia. The Yellow Sea green tide in 2008 caused direct economic losses due to damage to aquaculture, killing prawns and shellfish worth c. €86 million; the clean-up for the sailing event had an estimated cost of €200 million (Ye et al., 2011).

Green tides have significant effects on the major biogeochemical cycles of C, N, P and S. The algal mats stimulate ammonium and phosphate release that promotes their growth. During green tides, macroalgae sequester nutrients otherwise available for other primary producers (Valiela et al., 1997).

GREEN TIDES: THE CAUSE

The occurrence of green tides globally is linked to eutrophication, the increased nitrogen and phosphorus levels in coastal waters caused by human activities. Eutrophication is usually due to nutrients from agriculture. For example, in Denmark, more than 60% of the surface is agricultural, and 13 million pigs are produced p.a. (Bruhns, Aarhus University, conference abstract). In Britanny, France, the green tides due to nutrient inflows from pig farming have occurred over several decades, such that there is a recent French movie about them "Les algues vertes: 3 men and 40 animals were found dead on the Breton beaches ... a young journalist, driven by an ecological conscience, decides to go to Brittany to investigate".

In Europe, eutrophication is subject to control by the Nitrates Directive (with a derogation for agriculture in Ireland!!), and is regulated and monitored under the Water Framework Directive (2000/60/EC). The WFD focuses on the overall ecology and function of ecosystems in a holistic approach to the management of rivers, lakes, transitional and coastal waters. Significant pressures on water bodies must be identified and quantified - these include habitat loss, hazardous chemicals and eutrophication. Macroalgae form one biological quality element, and tools developed for coastal and transitional waters to determine eutrophication include monitoring mats of bloom-forming algae on sedimentary shores using both macroalgal biomass and cover to determine ecological status (Scanlan et al., 2007). High (reference) status is defined as <5% cover and <100 g m-2 on shore (so the green tides are clearly outside these values).

Internationally, the indicators for one of the UN's SDGs, 14. Life below water, refer specifically to "Coastal eutrophication: a growing threat to marine ecosystems and communities. Agriculture, aquaculture and wastewater practices are contributing to nutrient loading in coastal areas, causing widespread coastal eutrophication and algal blooms. These blooms lead to oxygen depletion, harm marine life, contaminate seafood, and damage seagrass and coral reefs, among other impacts. The consequences are severe for marine ecosystem health, local communities, fisheries and tourism."

GREEN TIDES: THE SOLUTION

The significant ecological, economical and social consequences of macroalgal blooms and dystrophy have caused considerable concern and resulted in the implementation of various attempted control measures. These management interventions fall into three main categories: algal harvesting, reduction of nutrient loads and improvements of water circulation to promote removal of nutrients and algal biomass. Implementation of these management strategies is extremely expensive (Fletcher, 1996), involving the removal of about 100,000 tonnes of seaweed per annum from recreational beaches of Atlantic France alone (Dion & Le Bozec, 1996). Also, they are often in response to specific catastrophic events, like the 2008 Yellow Sea bloom, and usually have had only limited success (Ye et al., 2011).

Over the last two decades, however, the increasing biotechnological value of *Ulva* species means that the vast biomass present in green tides can serve as valuable inputs for biorefineries, facilitating the production of fertilizers, biofuels, chemicals, food ingredients, and pharmaceuticals, horticulture and industrial applications (Ren et al., 2024). When the blooms are harvested this can potentially remove nutrients, restore habitats, and provide a cheap ingredient. *Ulva* species, particularly *Ulva lactuca*, are gaining popularity in a variety of industrial applications due to their high bioactive content and environmental benefits. These applications include uses in food, medicine, aquaculture, and environmental management, with potential for further growth.

Currently, *Ulva* species are used in the food industry as a healthy food source due to their high vitamin, mineral, and bioactive component content, which contributes to health advantages such as antioxidant and anti-inflammatory qualities. In pharmaceuticals, extracting bioactive chemicals from *Ulva* has the potential to aid in therapeutic development, notably for cardiovascular and neuroprotective health (Putra et al., 2024). *Ulva* is used in aquaculture as a natural growth promoter and immunological stimulant, answering the demand for long-term alternatives to antibiotics. Furthermore, in environmental management these algae can reduce nutrient pollution in coastal habitats, hence contributing to ecosystem restoration and sustainability (Blomme et al., 2023). In mariculture, *Ulva* is being explored as a model organism for sustainable mariculture, potentially revolutionizing coastal economies and food security (Buck & Shpigel, 2023).

GREEN TIDES: THE INDONESIA

The reviews of the global occurrence of green tides by Ye et al. (2011) and Ren et al (2024) do not mention any green tides in Indonesia, hence they appear not to have been reported frequently. However, as might be expected for a heavily populated coastline, green tides do occur in Indonesia. Ocean Harvest Technology's OceanFeed, a patented blend of red, green and brown seaweed formulated to support the healthy microbiome of livestock (https://oceanharvesttechnology.com), uses green tide *Ulva* mostly from Vietnam and Indonesia, and to a lesser extent from Zanzibar, in constituting its animal feed supplement.

To determine which species of bloom-forming species of *Ulva* are harvested in Indonesia, we obtained air-dried material of OHT's samples from Indonesia, Vietnam and Zanzibar. They were rehydrated in fresh water for morphological examination and for the preparation of voucher specimens.

Use of molecular identification methods is essential in *Ulva* owing to high morphological variability and lack of stable features. For this purpose, DNA was extracted in the Harries private lab and the *rbcL* gene (a chloroplast-encoded gene widely used for red and green algal systematics) was amplified and commercially sequenced as described by Maggs et al. (2004) (Figure 1). The Indonesian green tide samples were identified as *Ulva ohnoi*, a species originally described from Japan, that forms green tides throughout much of the world's tropical and warm-temperate coastal areas. The thalli are fragile but grow fast with rapid photosynthesis (Nakamura et al., 2019). The proliferation of *Ulva ohnoi* can lead to hypoxia and negatively affect marine biodiversity, similar to the impacts observed with *Ulva prolifera* blooms in other regions (Dong et al., 2023; Hiraoka, 2021).

In contrast, *Ulva ohnoi* presents ecological challenges; however, it can also offer advantages, including habitat for marine organisms and potential applications in aquaculture and biomass production. Consequently, the necessity of balanced management strategies is underscored.

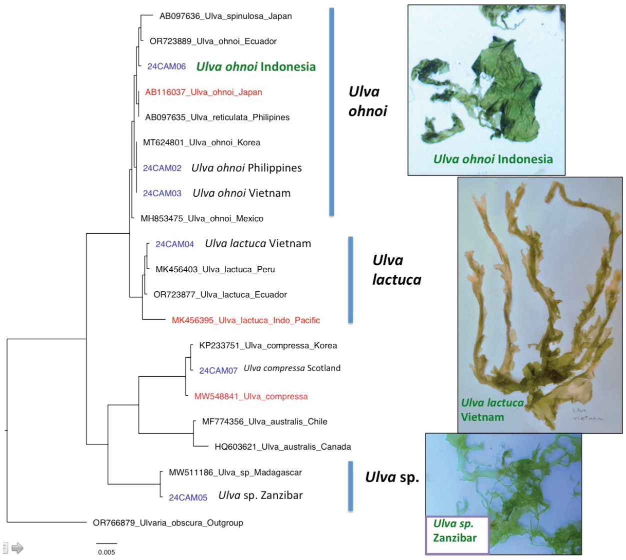

Figure 1. Analyses of *rbcL* gene sequences of *Ulva* from around the world, mostly in GenBank, showing their phylogenetic position and identification. CAM samples (codes in blue) from Indonesia, Vietnam and Zanzibar (purchased by Ocean Harvest Technology and newly sequenced) are identified as three different species, each with a clearly distinct morphology (images on right).

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CONCLUSION

Green tides, primarily *Ulva* species, are unattached blooms of green macroalgae that affect ecosystems globally. They can reach up to 27 kg wet weight m-2 and persist for up to a dozen years. The most significant blooms occur in the Yellow Sea, causing economic losses and disruptions in fishing and aquaculture activities. Green tides are linked to eutrophication, which increases nitrogen and phosphorus levels in coastal waters. However, the vast biomass in green tides can be used for biorefineries, fertilizers, biofuels, chemicals, food ingredients, pharmaceuticals, horticulture, and industrial applications. Ulva species are also being explored as a model organism for sustainable mariculture, potentially revolutionizing coastal economies and food security.

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REFERENCES

Blomme, J., Wichard, T., Jacobs, T., & DeClerck, O. (2023). *Ulva*: An emerging green seaweed model for systems biology. *Journal of Phycology, 59(3): 433-440.* doi: 10.1111/jpy.13341

Blomster, J., Back, S., Fewer, D.P., Kiirikki, M., Lehvo, A., Maggs, C.A. & Stanhope, M.J. (2002). Green tide conditions trigger novel morphology in *Enteromorpha*. *American Journal of Botany, 89:1756-1763.*

Bruhn, A. Conference abstract. Aarhus University.

Buck, B.H., & Shpigel, M. (2023). ULVA: Tomorrow's "Wheat of the sea", a model for an innovative mariculture. *Journal of Applied Phycology, 35(5): 1967-1970.* doi: 10.1007/s10811-023-03003-1

Dion, P., & Le Bozec, S., 1996. *The French Atlantic coasts.* In: Schramm, W., Nienhuis, P.H. (Eds.), Marine Benthic Vegetation: Recent Changes and the Effects of Eutrophication. Springer, Berlin, pp. 251–264.

Dong, S., Xin, Y., Liu, C., Xiao, Y., Feng, X., & Liu, T. (2023). Two treatment methods on *Ulva prolifera* bloom result in distinctively different ecological effects in coastal environment. *Frontiers in Marine Science, 10: 1084519.* doi: 10.3389/fmars.2023.1084519

Fletcher, R.L. (1996). *The occurrence of "green tides"- a review.* In: Schramm, W. & Nienhuis, P.H. (Eds.). Marine benthic vegetation: Recent changes and the effects of eutrophication. Ecological Studies 123. Springer-Verlag, Berlin. pp. 7-43.

Hiraoka, M. (2021). Massive *Ulva* green tides caused by inhibition of biomass allocation to sporulation. Plants, 10 (11): 2482. doi: 10.3390/PLANTS10112482

Leliaert, F., Malta, E.J., Engelen, A.H., Mineur, F., & De Clerck, O. (2008). Qingdao algal bloom culprit identified. *Marine Pollution Bulletin, 56: 15–16.*

Maggs, C.A., Bunker, A.R., Bunker, F.St.P.D., Harries, D., Kelly, J., Mineur, F., Blomster, J., Díaz-Tapia, P., Gabrielson, P.W., Hughey, J.R., & Brodie, J. (2024). Updating the Ulvaceae in the green seaweeds of Britain and Ireland. *Botanica Marina, 67: 1–20.*

Nakamura, M., Kumagai, N.H., Tamaoki, M., Arita, K., Ishii, Y., Nakajima, N., & Yabe, T. (2019). Photosynthesis and growth of *Ulva ohnoi* and *Ulva pertusa* (Ulvophyceae) under high light and high temperature conditions, and implications for green tide in Japan. *Phycological Research, 68: 152-160.*

Putra, N.R., Fajriah, S., Qomariyah, L., Dewi, A.S., Rizkiyah, D.N., Irianto, I., Rusmin, D., Melati, M., Trisnawati, N.W., Darwati, I., & Arya, N.N. (2024). Exploring the potential of *Ulva lactuca*: Emerging extraction methods, bioactive compounds, and health applications – A perspective review. *South African Journal of Chemical Engineering, 47: 233-245.* doi: 10.1016/j.sajce.2023.11.017

Raffaelli, D.G., Raven, J.A., & Poole, L.J. (1998). Ecological impact of green macroalgal blooms. *Oceanography and Marine Biology, 36: 97-125.*

Ren, C., Zhong, Z., Liu, Z., Lin, S., Luo, Y., & Qin, S. (2024). The ever-lasting green tides: What can we do?. *Heliyon, 10 (3): e25220.* https://doi.org/10.1016/j.heliyon.2024.e25220

Scanlan, C.M., Foden, J., Wells, E., & Best, M.A. (2007). The monitoring of opportunistic macroalgal blooms for the Water Framework Directive. *Marine Pollution Bulletin, 55: 162-171.*

Valiela, I., McClelland, J., Hauxwell, J., Behr, P.J., Hersh, D., & Foreman, K. (1997). Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. *Limnology and Oceanography, 42: 1105-A1118.*

Ye, N., Zhang, X., Mao, Y., Liang, C., Xu, D., Zou, J., Zhuang, Z., & Wang, Q. (2011). 'Green tides' are overwhelming the coastline of our blue planet: taking the world's largest example. *Ecological Research, 26: 477-485.* https://doi.org/10.1007/s11284-011-0821-8.