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Coastal restoration policy needs to consider seaweed diversity

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Seaweed diversity and biomass is in decline in many regions worldwide. In China, for example, 44% of seaweed species have become locally extinct around Yushan Island since 1989 (ref. 1); 286 species have been lost from Hainan since the 1970s[2]; and natural seaweed beds of *Sargassum horneri* in Nanji Islands have almost disappeared since the 1980s. These losses are alarming. Seaweeds (macroalgae) underpin rocky coastal ecosystems, where they provide habitat, food and spawning grounds, and drive nutrient cycling[3]. Seaweed species also benefit people as a direct source of food, medicines and chemicals, in addition to improving water quality and buffering storm surges[4,5]. Yet acknowledgement of the ecological and economic importance of diverse seaweeds is conspicuously lacking from high-level policy discussions. Specific attention to the sustainable use and safeguarding of seaweed resources and biodiversity is sorely needed.

The degradation and diminishing diversity of seaweed beds has led to weakened functions as habitat, spawning grounds and food sources for a wide variety of marine organisms. Declining seaweed diversity and biomass also triggers the occurrence of harmful algal blooms by creating conditions that are favourable for nutrient accumulation and reduced competition (Fig. 1a). These transregional macroalgal blooms (so-called green and golden tides of *Ulva* and *Sargassum* spp., respectively) can be up to 160,000 km^2 in area and usually persist for five to six months; they cause substantial alterations in the physical and chemical environments of seawater (for example, light, nutrients, dissolved oxygen and pH), and thereby exert an effect on regional ecosystems[6]. These enormous floating seaweed blooms can suffocate both wild and farmed marine organisms, and direct economic losses amount to several billion US dollars annually[7]. Upon stranding on beaches, massive seaweed blooms also impose multiple adverse effects on coastal ecosystems and socioeconomic activities. If not promptly removed, thallus decomposition can lead to the release of nitrogen and phosphorus, which exacerbates eutrophication processes, and the accumulating biomass can release toxic H_2S gas from the anoxic interior, which endangers terrestrial wildlife and humans[8].

There are several drivers of seaweed declines. Urbanization and coastal development (including construction of artificial structures such as seawalls, ports, piers, pontoons and mariculture rafts) have transformed natural habitats and environments (Fig. 1a). This sprawl of artificial shorelines is happening worldwide; in China, it has increased from 24% to 71% of the coast over the past four decades[9]. Many seaweed species do not survive in these artificial environments; this leads to diversity loss and macroalgal blooms — often of single species that can grow well in these altered habitats[10]. In addition, extreme weather events driven by climate change (such as marine heatwaves and storm surges) can decimate seaweeds by killing and removing them from hard substrata[11,12]. Seaweed species that trap gas for flotation (for example, *Ulva* and *Sargassum* spp.) can survive and drift on the sea surface; sinking and decomposition of species without this flotation can cause harmful reductions in oxygen levels. The overharvesting of edible species has also contributed to the sharp reduction in seaweed diversity, particularly on the extensive rocky shores of China.

Currently, there are no international laws, policies or targets that directly focus on seaweed diversity and very few countries consider them in their national policies. For example, in China, ecological protection and restoration in coastal zones focuses mainly on mangroves, saltmarshes, seagrasses and coral reefs, and a marine ranching initiative that involves the construction of artificial seaweed beds in the subtidal zone is centred on rehabilitating fishery production with no consideration for seaweed diversity.

We urge the Chinese government, and the governments of other coastal nations, to promptly take measures to augment seaweed diversity. Specific legal instruments could involve species and area-based listing methodologies, conservation and management strategies, regulations to govern use and harvesting, and restoration obligations. In terms of specific action, ecoengineering solutions are needed to modify present structures to support more natural biotic assemblages (Fig. 1b). These solutions include the use of alternative materials, modification of surface textures and mimicry of natural topographies, which can enhance the seaweed diversity of hard infrastructure while maintaining the functions of this infrastructure[13]. It is also necessary to establish areas where seaweeds are protected from harmful activities (such as overfishing, pollution and coastal development), while allowing for controlled sustainable use. The enhanced seaweed diversity (via ecoengineering solutions and establishment of marine protected areas) can then assist in preventing macroalgal blooms through interspecific competition. We also advocate for strengthening science education to raise public awareness of the importance of seaweed diversity and encourage people to become guardians rather than destroyers of seaweeds.

In addition to national policies, there is a pressing need to emphasize the importance of seaweed diversity in global marine conservation policies. Raising awareness can prompt stakeholders and policymakers to establish specific conservation targets for seaweeds and their habitats. Existing international bodies, such as the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP), should also integrate seaweed conservation into broader marine biodiversity initiatives. This approach could elevate the profile of seaweed in discussions of sustainable fisheries and coastal management. Meanwhile, recognizing and incorporating Indigenous and local knowledge into policy development can greatly enhance our understanding and management of seaweed biodiversity as local communities often possess invaluable insights regarding sustainable practices and ecosystem health, which can inform policies at national and international levels.

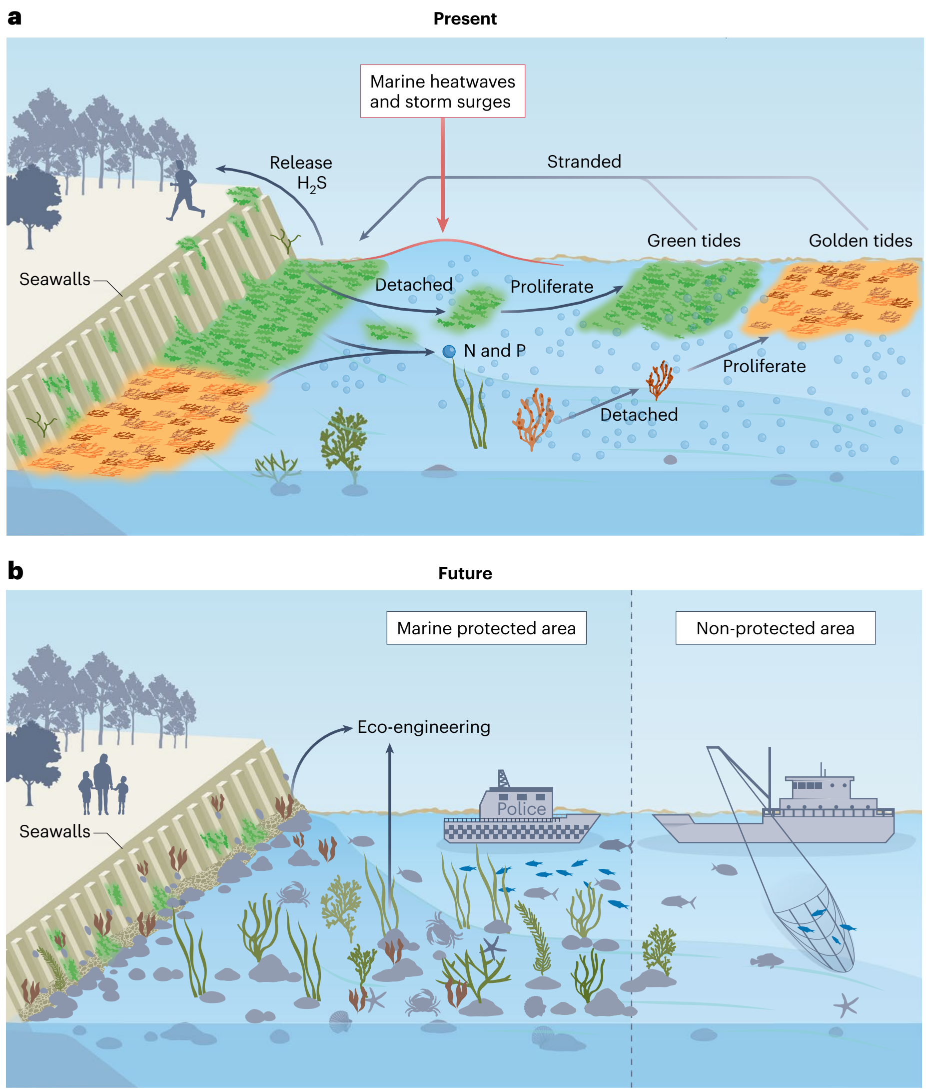

Fig. 1 | Restoring seaweed diversity to support coastal ecosystems. a, Seaweed diversity is currently decreasing and floating macroalgal blooms are increasing, owing to a combination of urbanization, eutrophication and extreme weather events (such as marine heatwaves and storm surges). Stranded and decomposing seaweeds release nitrogen and phosphorus into coastal waters, as well as toxic H_2S. **b**, Seaweed diversity can be restored and macroalgal blooms can be constrained in the future via ecoengineering solutions and the establishment of marine protected areas in intertidal and subtidal areas so that these areas can support diverse marine life and benefit people.

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Competing interests
The authors declare no competing interests.