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Maerl Bed Conservation: Successes and Failures

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ABSTRACT

Most ecoregions lack data on maerl distribution and ecological status, so this needs fundamental research for conservation. Brittany, NW France, is an exception and has extensive research on maerl species, associated biodiversity, human-induced impacts and protection efforts. Breton maerl habitats host exceptionally high species richness and functional diversity, surpassing all other coastal habitats in the region. The meiofauna and microflora of maerl beds and the role of these habitats as carbon stores remain poorly known. Bans on direct exploitation in Europe have led to environmental improvements, although maerl extraction has begun in other regions of the world. In Europe, serious maerl conservation problems persist, particularly due to scallop and clam dredging, eutrophication and mariculture impacts. Not enough has been done to curb these issues, which are proven to severely degrade maerl, its biodiversity and ecosystem functions. Conservation measures for maerl beds should be strengthened and codesigned with local stakeholders as these habitats take millennia to form and are inadequately protected by current strategies.

1 | Introduction

Maerl beds are of enormous ecological importance in extensive areas of sunlit marine coastal waters worldwide (Tuya et al. 2023). These calcified coralline algal habitats store carbon in the seabed and help keep the seawater and seabed oxygenated and clean (Schubert et al. 2024). They have exceptionally high levels of biodiversity and provide spawning/nursery areas for economically important species of fish (like herring and cod in the Atlantic Ocean basin) and broodstocks of large, edible crustaceans and bivalve molluscs (Hall-Spencer, Kelly, and Maggs 2010). The maerl slowly builds a type of rhodolith habitat in which the coralline algae are unattached, that is, they do not grow around stones or shells (Leite Jardim et al. forthcoming). They have withstood millennia of coastal storms and shifting currents, but since the 1950s, demersal fishing, sedimentation from land due to industrialised farming, eutrophication, sewage pollution and mariculture have all increased impacts in coastal waters (Steffen et al. 2015) causing global declines in maerl extent and quality.

A special issue on maerl (Donnan and Moore 2003) was based on discussions about 'The scientific basis for the conservation management of maerl grounds' and involved researchers from Europe and North and South America. It revealed that maerl is highly vulnerable to human activities and informed conservation policy. Riosmena-Rodríguez, Nelson and Aguirre (2016) went on to explain that these habitats document past climatic and environmental conditions and shape present-day ecosystems by increasing seabed biodiversity in the photic zone. They reiterated the threats to maerl from direct exploitation through extraction and bottom-towed fishing gear. They also added new information about the effects of pollution, sea surface warming and ocean acidification—emphasising the need to avoid long-lasting damage to maerl beds.

Maerl beds remain much less well-known than other iconic habitats, such as coral reefs, sea-grass meadows and kelp forests. Most ecoregions lack information about maerl distribution and its ecological significance and so require fundamental research to support outreach and conservation (Tuya et al. 2023). Brittany (in NW France) is an exception, thanks to a long history of research that has provided a detailed understanding of the maerl species present and their associated biodiversity (Figure 1). Brittany has well-documented impacts of human-induced pressures and has made efforts to protect maerl. Here, we reflect on the successes and failures of those efforts since we published 'Problems facing maerl conservation in Brittany' (Grall and Hall-Spencer 2003).

2 | Maerl Biodiversity

The taxonomy of maerl-forming species in Brittany has remained stable over the past 25 years; the main species are still described as *Phymatolithon calcareum* and *Lithothamnion corallioides* (the only maerl-forming species listed in the EU Habitats Directive 92/43/EEC), together with rare occurrences of *Lithophyllum fasciculatum* (Peña et al. 2013). Elsewhere, there has been less taxonomic stability. For example, at the turn of the century there was doubt over whether *L. corallioides* could occur as far north as Scotland and what was then called *Lithothamnion glaciale* is now known to be a mix of both *Boreolithothamnion glaciale* and *Boreolithothamnion soriferum* (Gabrielson et al. 2023). *Phymatolithon lusitanicum* has not yet been found in Brittany, despite efforts to find it using morphological studies and genetic barcoding, but it may be there given that this species occurs in Galicia (Spain) and the United Kingdom (Peña et al. 2015).

Breton maerl beds host a remarkable number of species, always surpassing that of surrounding coastal sedimentary habitats such as intertidal sediments, sea-grass beds (*Zostera marina*) and subtidal sediments (see Boyé et al. 2019). The flora has been surveyed extensively since the first studies by Lemoine (1910) and has several maerl specialist species (viz. *Cruoria cruoriaeformis*, *Cladophora rhodolithicola* and *Gelidiella calcicola*). Peña et al. (2014) and Helias et al. (2024) document the high diversity and distinct assemblages of macroalgae on maerl. To date, 174 macroalgal species have been recorded on Breton maerl, which is an outstanding 42% of the total regional seaweed diversity (Helias and Burel 2023; Helias et al. 2024). Normally (but see the eutrophication section below), the biomass of noncalcified seaweeds on maerl remains low due to grazing and mobility of the surface layer, although kelp can be conspicuous and transports clumps of maerl in its holdfasts in storms. Micrograzers, such as juvenile sea urchins and the small limpet *Acmaea virginea*, help keep maerl surfaces clean by feeding on diatoms and other microalgae. The microflora on (and the endoliths that live in) maerl are probably diverse (Aude Leyneart pers comm.) but remain unstudied.

FIGURE 1 | Healthy Breton maerl bed showing associated biota, particularly the sponge *Haliclona simulans*, ophiuroids, ascidians, epiphytic macroalgae and a cuttlefish egg mass.

There are around 2000 macrofaunal taxa recorded from maerl beds between Galicia (Spain) and the Lofoten Islands (Norway) (Grall and Hall-Spencer unpublished data). This outstanding tally exceeds that of other habitats and underscores the ecological richness of maerl beds. No animal species is known to be endemic to maerl, instead species with affinities for mud, sand or gravel coexist alongside species that prefer hard substrata, such as shells or rock (Foster 2001; Grall and Glémarec 1997; Grall et al. 2006). This cohabitation of taxa reflects the fact that maerl beds are heterogeneous, dynamic habitats with an exceptional diversity of species spanning primary producers, grazers, surface and subsurface detritus feeders, active and passive suspension feeders, predators, scavengers and parasites (Boyé et al. 2019).

Breton maerl beds harbour all the major phyla, with red algae, annelids, crustaceans, and molluscs as the most abundant and species-rich groups, typically alongside a diverse array of sponges, cnidarians and fishes. Their meiofauna is poorly known, but a study focusing on nematodes revealed a high diversity in maerl beds compared with other sediment habitats (Rebecchi et al. 2022). Other meiofaunal groups, such as harpacticoid copepods, are also often abundant in maerl habitats (pers obs.). As meiofauna are crucial to nutrient cycling and energy flow in many marine systems, their role in maerl beds warrants further study.

Boyé et al. (2019) assessed the taxonomic and functional diversity of polychaete assemblages in maerl and other sedimentary habitats around Brittany. The maerl beds had significantly higher species richness and functional diversity than sea-grass beds and other sedimentary habitats (Figure 2). The worms had distinct ecological niches facilitated by high habitat complexity. Maerl-forming algae provide habitats that shape benthic assemblages and contribute significantly to regional biodiversity (Boyé et al. 2019; Bulleri submitted). The strong correlation between species richness and ecosystem functioning (e.g., productivity) is well-established (Wagg, Roscher, and Weigelt 2022) and applies to maerl beds. Although some species that live on or in maerl beds have key roles (e.g., in fixing carbon or cycling nutrients), the loss of others may have negligible consequences for overall ecosystem function. Knowledge of maerl beds and their inhabitants, such as their role as nursery areas for commercially important species of shellfish and fish, can inform conservation and management efforts (Kamenos, Moore, and Hall-Spencer 2004a, 2004b).

Maerl beds provide a wide variety of microhabitats that may be important refugia for biodiversity in the face of climate change, by strengthening the resilience of marine ecosystems. In the following sections, we examine specific threats to Breton maerl bed biodiversity from direct extraction, invasive species, eutrophication/organic enrichment, scallop/clam fishing and climate change/ocean acidification.

3 | Maerl Extraction

In the 20th century, maerl was dredged up from the seabed around Brittany (as well as in Ireland and England) for a variety of uses on land, but mainly to improve soil for agriculture. Extraction involved washing the maerl at sea which released fine particles that smothered and killed live maerl and altered associated communities over much wider areas than the extraction zones. Extraction far exceeded the regeneration capacity of live maerl and was shown to be ecologically unsustainable (Donnan and Moore 2003). In Glénan (South-West Brittany), where maerl had been extracted for over 45 years, radiocarbon dating showed that early Holocene deposits of the maerl had been exposed leaving the seabed with almost no live maerl left and a very impoverished benthic community (Grall and Hall-Spencer 2003). Maerl extraction caused beach erosion. Beach erosion followed the extraction of more than 500,000 tons of maerl every year just north of the Glénan Islands (less than a kilometre away). The resulting pit filled with surrounding sediments, altering the local sedimentary balance and causing the beaches (which are composed of maerl) to recede. This is an aspect that was not adequately addressed in assessments of the environmental impacts of maerl extraction.

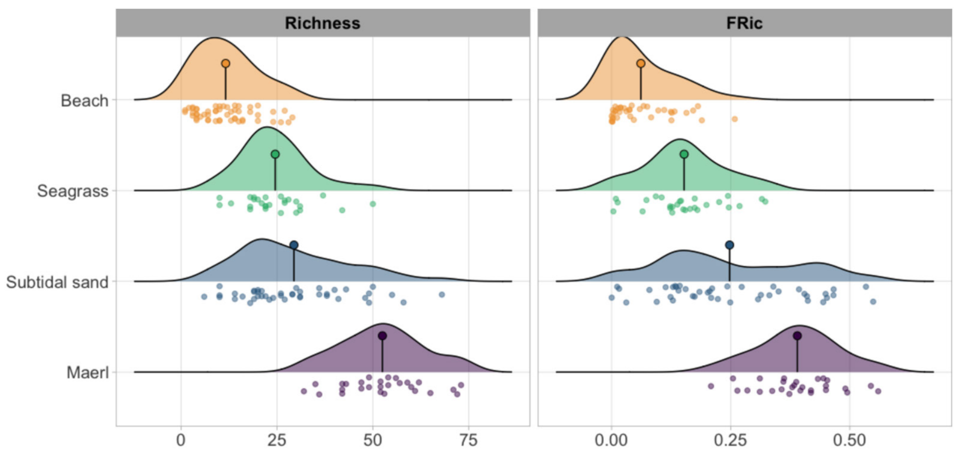

FIGURE 2 | Polychaete taxonomic diversity (richness) and functional diversity (FRic) based on polychaete traits in four habitats around Brittany. Data from 15 years' worth of surveys of 14 beaches, 9 intertidal sea-grass beds, 12 subtidal sand and 10 subtidal maerl beds, see Boyé et al. (2019). For each habitat, the distributions include the values of the different sampled sites with, for each site, values for the 3 years (2007, 2010 and 2013). The mean value for each of these indices is represented by the point pinned on each distribution. Figure redrawn from Boyé (2018) with the author's permission.

Conflicts between fishermen and maerl extractors came to a head once several Breton maerl beds had been destroyed and word had spread about the adverse impacts on bivalve nursery areas. Stricter regulations were imposed in Brittany in the early 2000s, and in nearby Falmouth (England), extraction was banned to stem marine environmental decline (Hall-Spencer 2005). Plans to dredge maerl to deepen a shipping route for cruise ships into Falmouth stalled when a study revealed live maerl in the proposed route (Sheehan et al. 2015). This study showed that if maerl was temporarily removed from the surface and relaid in the dredged channel then much of the short-lived fauna would rapidly recolonise. Breton authorities imposed a ban on all maerl extraction in 2011 but large scale maerl/rhodolith extraction has since started in Brazil (https://croixblanchepharma.com/produit/lithothamne-100-gelules-dosees-a-850mg/) and Iceland (https://roches-marines.fr/articulations/55-56-lithothamne.html) where companies selling maerl products promote the purity of the environment where it lives but do not inform customers about the unsustainable nature of strip-mining this ancient biogenic habitat. A cycle of scientific evidence gathering and socioeconomic debate will need to begin to determine the fate of these coastal marine habitats.

The benefits of ceasing maerl extraction in the United Kingdom are not known as there are no follow-up studies to date, but at Glénan, there were significant improvements (Tauran et al. 2022). When dredging stopped seawater turbidity decreased around the extraction zone and live maerl started to very slowly recover (at a rate of ~0.5% per year): it may take 50–100 years for live maerl to reach pre-industrial exploitation live maerl levels (Figure 3). Recolonisation mechanisms, such as in situ live thalli growth, colonisation of dead thalli by maerl spores, the natural import of live thalli from adjacent areas or the efficacy of active habitat restoration, are unknown and require research.

The maerl bed community has improved at the Glénan site, 20 years after the extraction ban. There are now significantly reduced levels of fine particles in the sediment but the habitat remains primarily composed of dead and broken maerl branches, holding back full recovery to the species-rich communities that are typical of undredged maerl. Significant recovery is evident, with the return of commercially important juvenile bivalves (*Pecten maximus*, *Aequipecten opercularis*, *Paphia rhomboides*, *Venus casina*, *Tellina crassa*, *Spisula solida*). The previously dredged maerl has seen a return of the sea urchin *Sphaerechinus granularis*, leading to a reopening of a fishery for it on the maerl in 2017. Halting maerl extraction at Glénan has led to significant environmental improvements, although there is still work to be done to assess whether restoration of this valuable coastal habitat has reinstated its benefits as a fish nursery area (Kamenos et al. 2004a,b).

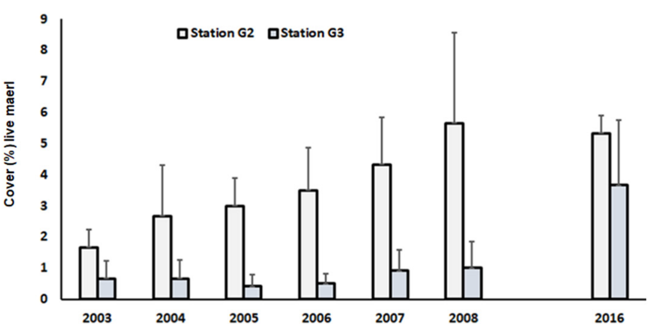

FIGURE 3 | Cover (%) of live maerl following an extraction ban in Glénan at two different stations in Glénan 13 years after the ban. It highlights the slow recovery of maerl together with the spatial variability at the maerl bed scale. Recovery is a long way off the 70%–100% live cover found on undredged maerl beds around the Glénan archipelago.

4 | Invasive Species

Eleven non-native species of macroalgae have been recorded on Atlantic European maerl beds, the most widely distributed being *Bonnemaisonia hamifera*, *Asparagopsis armata*, *Antithamnionella spirographidis* and *Heterosiphonia japonica* (Peña et al. 2014). Opportunistic filamentous algae can become very abundant in spring and summer in areas affected by eutrophication. A few non-native macrofauna are present in Breton maerl beds (*Chaetozone corona*, *Styela clava*, *Watersipora subatra*), but they occur in low abundances. Even near areas heavily colonised by these species, such as ports and shellfish farming zones, their abundance remains low in maerl beds.

There were concerns that the slipper limpet, *Crepidula fornicata*, would cause long-term damage to maerl habitats (Grall and Hall-Spencer 2003). Introduced to France in the mid-20th century, it smothered some areas of the seabed, reducing scallop populations and lowering biodiversity (Jardim et al., this issue). In the Bay of Brest, *C. fornicata* peaked at 10% cover of the entire bay in 2002–2006 but never reached densities > 30 ind./m^2 on maerl beds. In the Bay of Saint-Brieuc and the Normano-Breton Gulf, *C. fornicata* caused widespread problems but did not establish significantly on Breton maerl beds. Bunker and Ratcliffe (2024) have been monitoring *C. fornicata* outbreak on maerl beds in Milford Haven (Wales) for 20 years, where the spreading also reached a pike (2016) before subsequently declining.

5 | Organic Enrichment and Eutrophication

Urban, agriculture and mariculture waste waters have degraded many maerl beds. Organic enrichment is particularly detrimental to rare and larger species and favours small opportunistic fauna (Pearson and Rosenberg 1978). Maerl health status has radically improved over the past 20 years in the northern basin of the Bay of Brest, following measures taken to separate sewage and rainwater and to modernise sewage treatment plants. The biomass of fleshy macroalgae significantly decreased (Helias et al. 2024), and biodiversity has increased by around 30%, particularly amongst the infauna, where the proportion of opportunistic species has decreased significantly (Tauran et al. 2022). Commercially valuable species (e.g., *Venus verrucosa* clams, *Cerastoderma edule* cockles and *A. opercularis* queen scallops) have returned and the amount of living maerl has increased over time, possibly due to recolonisation of dead maerl thalli by spores (Tauran et al. 2022).

Nutrient concentrations, although lower than before, are still high and so the area has more macroalgal biomass than is normal, probably because large sea urchins remain absent probably due to organic pollution in the bay (Guillou et al. 2000). So although the problem is not entirely solved, significant progress has been made. Many rural households in the region release untreated sewage causing hypoxia (or even anoxia) at the sediment water interface in the warmest months. Affected maerl beds have had high maerl mortality and major reductions in biodiversity and ecosystem function. Improved wastewater treatment is needed for the catchments of these semi-enclosed seawater areas requiring management decisions that are decades overdue.

Nutrient inputs (e.g., from NPK agricultural fertilisers) cause 'green tide' blooms of *Ulva* spp. every year since the 1990s (Quillien et al. 2015). The decomposing algal mats reduced benthic biodiversity and cause a proliferation of opportunistic species through the same ecological mechanisms that drive changes to the benthos affected by organic enrichment from sewage (Grall and Chauvaud 2002; Pearson and Rosenberg 1978). In the Gulf of Morbihan, and in the bays of Brest, Morlaix and Concarneau, maerl beds are now eutrophic. Areas with sufficient sea urchins do not have the obvious high macroalgal biomass symptoms of eutrophication, but in heavy metal-polluted zones, or those impacted by towed demersal fishing gear, opportunistic uncalcified macroalgae bloom due to a lack of grazing (Figure 4).

Diverse and abundant epifauna can occur on maerl grounds affected by macroalgal blooms. The twiggy maerl structure helps maintain water circulation and prevents hypoxia at the water-seabed interface, but a build-up of rotting fleshy seaweed causes anoxia in the subsurface layer. Here, opportunistic infaunal

FIGURE 4 | A eutrophic maerl bed at 2 m below chart datum in the Bay of Brest showing unusually large amounts of macroalgae in winter (A February 2016) and a bloom completely smothering the maerl community in summer (B July 2016).

polychaetes (such as *Capitella capitata*, *Chaetozone* spp. and *Cirriformia tentaculata*) become dominant, feeding on the decomposing algae. This disrupts ecosystem functioning, reducing bioturbation and nutrient cycling and shifting the trophic structure towards deposit feeders and negatively impacting water quality control by suspension feeders (Ragueneau et al. 2018).

Mariculture is expanding rapidly worldwide degrading maerl beds at several locations (Legrand et al. 2024) although this seems not to be a pressing issue in Brittany. Extensive long-term mussel farming in Galicia has reduced live maerl cover and altered maerl bed communities through increased sedimentation, shading, anchoring and fallen mussel shells (Peña and Bárbara 2008). Atlantic salmon farms in Scotland and Norway are degrading maerl beds through organic pollution and the effects of organophosphate nerve poisons that target salmon lice but kill a wide variety of crustaceans (Hall-Spencer and Bamber 2007; Legrand et al. 2024).

6 | Scallop and Clam Fishing

The known adverse impacts of towed demersal fishing gear (Donnan and Moore 2003) has informed maerl conservation policy, such as in the Bay of Brest, and in other large maerl beds sites such as around the Glénan Islands and in the Iroise Marine Park. The Bay of Brest has the most well-known and best monitored maerl habitats in France and highlights a spectacular failure in maerl conservation policy. Over a third of the maerl beds in the bay have been lost due to towed demersal fishing gear in the past 10–12 years (Bernard et al. 2019; Tauran et al. 2022). Maerl bed destruction by low profit/high carbon footprint clam dredging needs to be phased out.

For centuries, the main target of fishing vessels in Bay of Brest was the King scallop *Pecten maximus*, shifting from sail to engine power in the 1950s. A *Pseudo-nitzschia* bloom in 2004 caused amnesic shellfish toxins from the diatoms to persist in the scallops for months to years (Blanco et al. 2002; Garcia-Corona et al. 2024). The fishery was closed as a result, so fishermen switched to harvesting *Venus verrucosa* clams, which live deeply embedded in the maerl beds. Recurrent *Pseudo-nitzschia* episodes between 2008 and 2018 intensified the shift from scallop to clam harvesting. After 2018, the ban on scallop fishing was lifted, and the maerl habitats are now (in 2024) exploited both by scallop and clam dredging.

Fishing damage to maerl beds has negatively impacted the ecological functioning of the Bay of Brest. Maerl beds can sequester and store silica through the growth of sponges (Figure 1), but

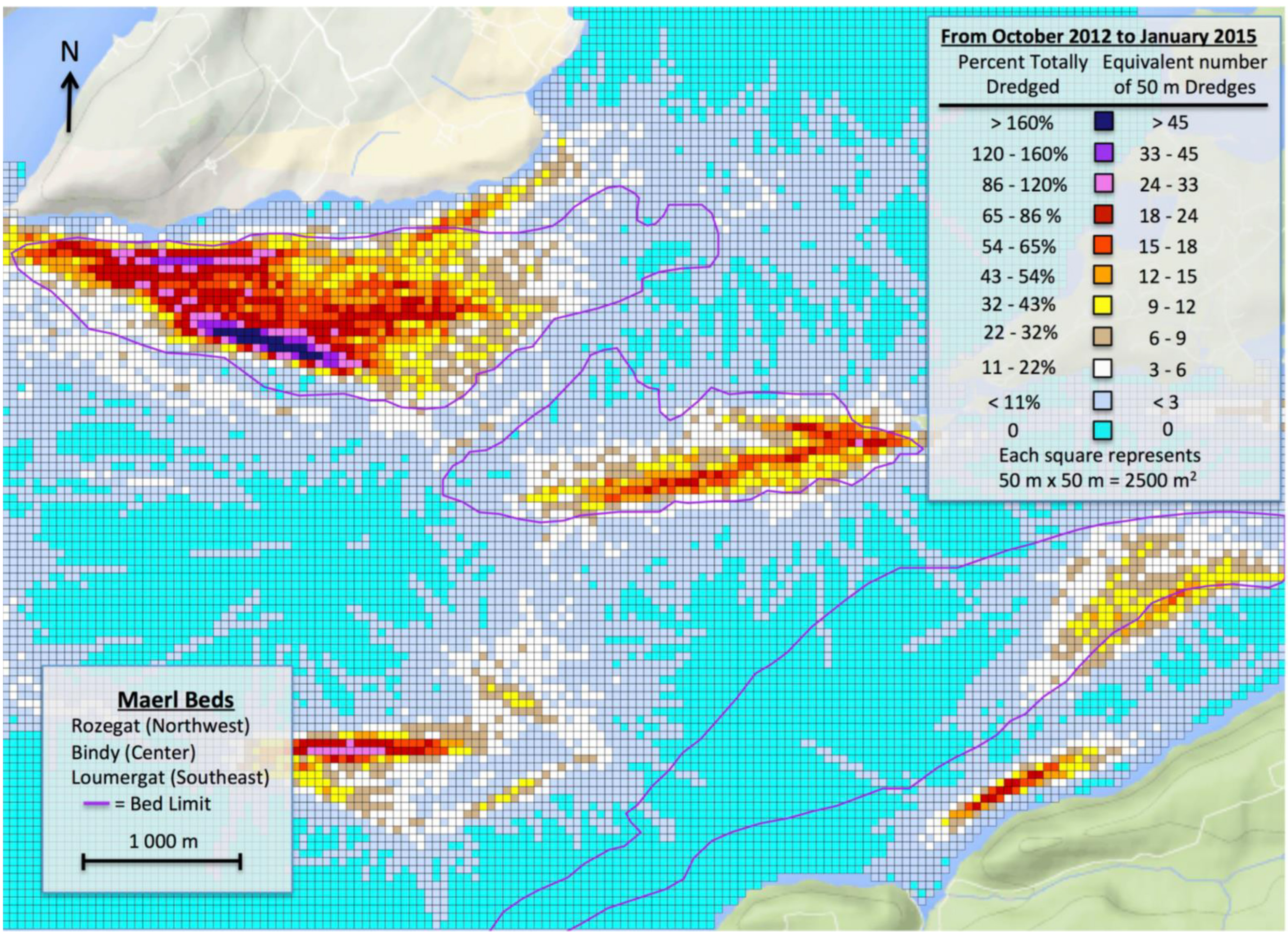

FIGURE 5 | Fishing pressure, based on automatic identification system data, from clam fishing vessels dredging maerl beds in the Bay of Brest, showing the number of times 50 × 50 m zones were dredged between 2017–2022. Shading is the land; insert shows the location of the Bay of Brest in Brittany, France.

their destruction is thought to contribute to the proliferation of *Pseudo-nitzschia* blooms by releasing the silica, locking the system in a cycle of poor environmental status (López-Acosta et al. 2022; Ragueneau et al. 2018). Maerl beds also sequester and store inorganic carbon, which can buffer the adverse effects of ocean acidification and improve bivalve mollusc growth (Martin and Hall-Spencer 2017), and they can accumulate considerable amounts of organic carbon through settlement and trapping of organic matter between and underneath the calcareous thalli, which can be stored in deposits they create over millennia (Mao et al. 2020). Towed demersal fishing gear releases seabed carbon stores due to sediment mixing and damage to biological communities (Hiddink et al. 2023), although the amount of labile carbon that is stored in Breton maerl beds and the amount that is released when a maerl bed is dredged for bivalves is unknown.

Automatic identification system vessel tracking data show that some maerl grounds in the Bay of Brest are heavily fished while others experience minimal disturbance (see Bernard et al. 2019; Tauran et al. 2022; Figure 5). In heavily fished zones, clam dredging has pulverised large maerl thalli and pelites (e.g., clumps of mudstone), breaking them into fragments, with a major reduction in live maerl coverage. Areas with low clam dredging pressure had more live maerl, more sediment heterogeneity and fewer broken maerl thalli with higher total species richness, and more rare species (Tauran et al. 2020, 2022), which is consistent with research into bivalve dredging on maerl beds elsewhere (Hall-Spencer et al. 2003; Hauton, Hall-Spencer, and Moore 2003).

The environmental quality indicators AZTI's Marine Biotic Index (AMBI) and Multivariate-AMBI (Sigovini, Keppel, and Tagliapietra 2013) classified all maerl beds in the Bay of Brest as in 'very good' condition and so were not useful for assessing fished maerl habitat state, but the analysis of grab samples using the General Purpose Biotic Index (Labrune et al. 2021) did capture the differences between clam dredged and undredged maerl beds. Other ecological assessment tools are being developed that minimise harm to maerl bed ecology. Coquereau et al. (2017) tested whether bivalve dredge fishing would affect maerl soundscapes because bivalve dredge fishing damages maerl bed structure and associated communities (Hall-Spencer et al. 2003) and soundscapes had been used as a proxy for marine health status on other habitats (Harris, Shears, and Radford 2016).

In the study of Coquereau et al. (2017), recordings were made on a heavily bivalve dredged, and an undredged maerl bed in spring and autumn and grab samples of the soniferous fauna were taken. In both seasons, ambient noise levels were around three times louder and were far more diverse on the unfished maerl bed than on the clam dredged bed (Figure 6). Just as birdsong is muted in urban areas but loud and diverse in the countryside,

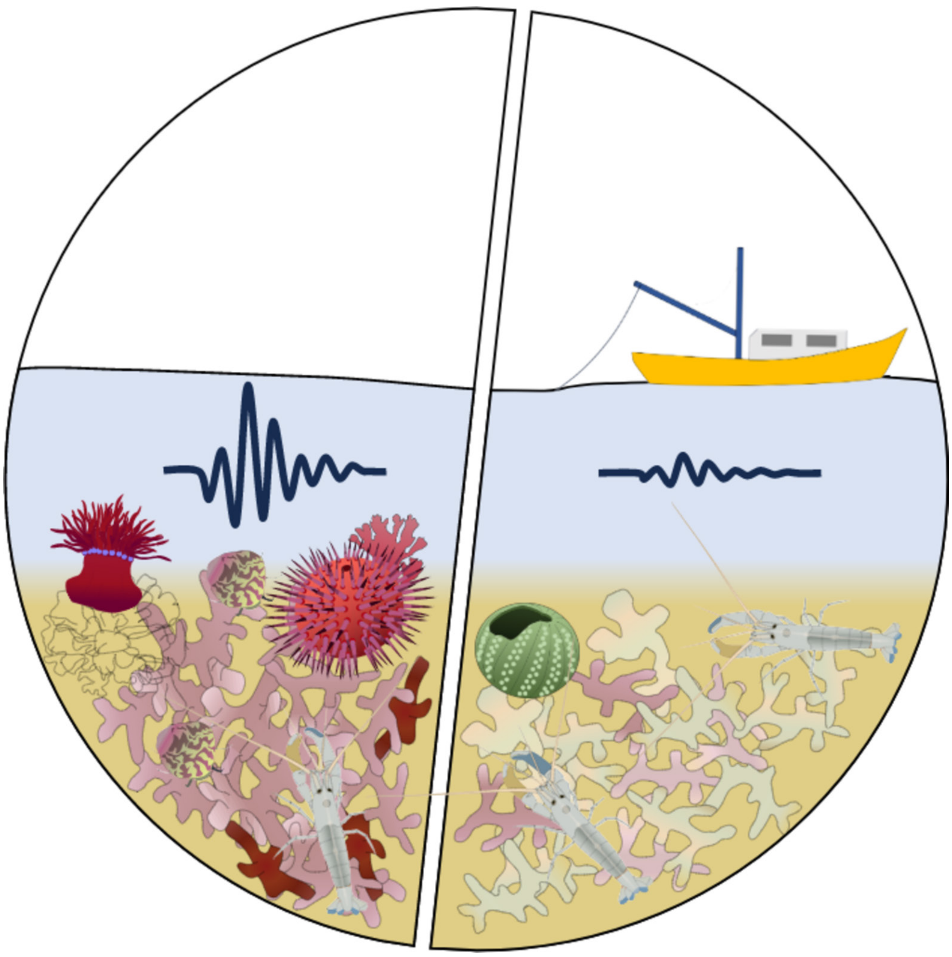

FIGURE 6 | Lines represent sounds produced by maerl residents. Healthy maerl beds are noisy but those damaged by clam dredging are much quieter. Schematic by Anaelle Bizien after Coquereau et al. (2017).

there were significantly fewer and less diverse soniferous organisms in the heavily fished maerl bed. The soundscapes were reliable indicators of maerl biodiversity status with noises made by snapping shrimps, sea urchins and squat lobsters as the main contributors to observed differences between fished and unfished beds. This approach could be applicable to other maerl/rhodoliths beds impacted by fishing.

Another nondestructive approach for maerl assessment uses Sediment Profile Imagery to take in-situ cross-section images to check habitat structure. This can be used to assess biodiversity and ecosystem functioning over time. Bernard et al. (2019) used this technique to quantify the impact of bivalve dredging on maerl beds in the Bay of Brest along a fishing pressure gradient. They measured the physical structure and live:dead thalli ratio of the maerl beds and showed that as dredge fishing intensity increased, there was a decrease in sediment profile image penetration depth due to compaction of the maerl bed. Moderate dredging intensities created a mosaic of patches with varying impacts, while high intensities homogenised the seascape. Surface rugosity decreased even with low dredging intensity as the complex structure of maerl was easily impacted by towed demersal fishing equipment. The ratio of live:dead maerl showed a clear response to dredging pressure, following an exponential decrease towards zero. This underscores the significant impact of physical disturbance on maerl even at moderate levels of fishing intensity. Clam dredging buried maerl in a thick layer of broken dead maerl fragments.

7 | Climate Change/Ocean Acidification

There are concerns that future ocean acidification and warming may impact maerl beds in Brittany through increased noncalcareous macroalgal productivity and reduced maerl calcification rates (Legrand et al. 2017), although Brodie et al. (2014) estimate that carbonate levels will remain high enough to avoid dissolution of the maerl habitats in this region. Most studies show that coralline algal calcification is adversely affected under near-future ocean acidification scenarios and that in combination with a 1°C–3°C increase in seawater temperature this has an even larger impact (Martin and Hall-Spencer 2017). Studies in areas with naturally high CO2 levels show that coralline algae are adversely affected by long-term acidification through increased competition from noncalcified competitors (Cornwall, Comeau, and Harvey 2024). Regional assessments are needed to

FIGURE 7 | Live pink maerl cast up and stranded in the intertidal zone following storm Ciarán in November 2023 at ROZ bay in Logonna-Daoulas (Bay of Brest). This happened along miles of foreshore in the western part of the bay. The orange balls are *Tethya citrina* sponges that are rare and considered in need of protection in France; the maerl and these sponges subsequently died due to desiccation.

determine whether management policies are likely to be effective in the face of global change impacts on maerl beds (Qui-Minet et al. 2019). Published studies to date indicate that ocean acidification and warming are not a primary concern for the maerl flora in Brittany.

Being mobile, live maerl thalli can be displaced by storms to areas where the coralline algae cannot survive, such as deep water, onto the shoreline (Figure 7) or buried in sediment. They can also become widely dispersed by storms onto other shallow water habitats so that they no longer function as maerl beds. As storms are expected to multiply and increase in intensity (Mendez-Tejeda and Hernandez-Ayala 2023; Wolf, Woolf, and Bricheno 2020), some maerl beds, especially the shallower ones (Bélanger and Gagnon 2023), could suffer.

8 | Successes and Failures to Conserve Maerl

The benefits of maerl beds for biodiversity, as nursery grounds, as carbon sinks and as regulators of water quality, are increasingly recognised (Tuya et al. 2023). In Europe, maerl has been used as a feature for the designation and management of a network of marine protected areas with promising signs that citizens are now lobbying to ensure that these designations are not just 'paper parks' but that they deliver on maerl bed conservation (Hall-Spencer and Rasmusson 2024).

In Brittany, there is extensive detailed knowledge about maerl beds, making them probably the best-understood beds globally. Studies have detailed their biodiversity, dynamics and functioning, highlighting their sensitivity to damage and extremely slow recovery rates. Precise mapping and monitoring have documented the locations and status of these beds. In parallel, public awareness has increased, with maerl bed exhibits now in local aquaria and there is even a maerl festival held in Plougastel-Daoulas (Western Brittany) that emphasises the need for protection.

A ban on maerl extraction and improved waste water treatment has allowed some Breton maerl beds to recover over the past 20 years, yet highly damaging clam dredging and poor waste water treatment is causing a continued decline in maerl ecological status. Policymakers must be convinced to prioritise long-term ecological benefits over short-term gains, requiring robust and effective conservation measures. These measures should be codesigned with local stakeholders to ensure practical strategies that are well supported by the public.

Enhanced enforcement of regulations and the development of new policies are needed to mitigate the impacts of clam dredge fishing and poor water quality. Investing in restoration projects, monitoring and scientific research could reverse the decline. Brittany's experience shows that comprehensive knowledge and public support must be backed by strong political action to achieve effective conservation.

9 | Conclusions

Ongoing threats to maerl biodiversity and ecosystem function underscore the urgent need for conservation efforts. Protecting these habitats involves regulating damaging activities, reducing pollution and promoting sustainable practices. By safeguarding maerl beds, we preserve their biodiversity and ecosystem functions.

In the past 20 years, a ban on direct removal of maerl for use on land was a big conservation win for France and the UK, but the fact that it has started up in Brazil and Iceland shows there is still demand for exploitation that is unsustainable due to the slow growth of the coralline algae that form the deposits. Threats to maerl from bottom-towed fishing gear and eutrophication remain severe. These are significantly reducing local biodiversity because maerl provides habitat for so many species of algae and animals, several of which are economically important (Bulleri et al. 2024).

Conservation measures need to go further as, unlike most marine habitats, maerl beds take decades–millennia to build. Maerl habitat restoration is an untested concept and may not work given the extremely slow growth of thalli. What is more tractable is to map all maerl beds, assess their status and if possible their associated biodiversity and ecosystem services, evaluate the anthropogenic pressures they face and negotiate on a case-by-case basis the reduction of these pressures. Given the diversity of threats to maerl beds globally, conservation measures codesigned with local stakeholders are needed to secure their beneficial role in the functioning and biodiversity of coastal ecosystems.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The complete data from the REBENT monitoring programme (http://www.rebent.org) are available in the Quadrige database (http://envlit.ifremer.fr/resultats/base_de_donnees_quadrige) and in the database of the marine observatory of the IUEM (available upon request: https://www-iuem.univ-brest.fr/observatoire).

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